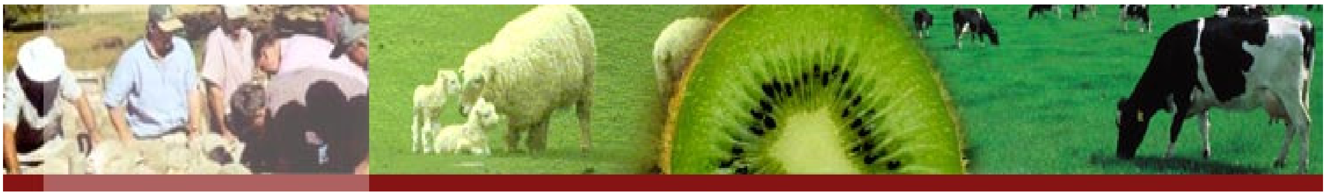
AGRICULTURE RESEARCH GROUP ON SUSTAINABILITY



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Cleaner streams and improved stream health on North Island dairy and South Island sheep/beef farms

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Executive Summary

One of the most important environmental, political and economic issues surrounding agriculture is the impact and interdependence of intensive agricultural production on water resources. There is a growing body of evidence that links agricultural production with reduced water quality and degraded ecological communities in farms streams. In New Zealand the majority of agricultural pollution comes from diffuse, non-point sources, and most commonly takes the form of inputs of excess nutrients, sediments and micro-organisms. Habitat change due to clearing, channel modification, and drainage also contribute to diminished water quality in most NZ agricultural landscapes.

Agricultural impacts on aquatic ecosystems occur at a range of scales from individual sites on waterways to whole-catchment effects of land management practices. Theoretical and practical knowledge on how to reduce impacts on water quality and aquatic ecosystem functioning focuses on reducing flow of pollutants into waterways. Fencing of waterways to exclude stock access, retention of grassy buffer strips, planting of riparian vegetation to increase shading and reduce sediment and nutrient entry, and the careful management of livestock wastes can all reduce agricultural impacts on waterways. Several national and local government, NGO and industry level reports and actions are dedicated to improving stream health in production landscapes.

Demonstration of scientifically defensible and ongoing monitoring of stream health could add safety to New Zealand's agricultural market access and allow product price premiums. Accreditation systems for Integrated Management and organic farming could improve stream health. Increasingly stringent agricultural product import stipulations are likely to require stream health impact assessments. The Agricultural Research Group on Sustainability (ARGOS) performed this study as the first step in a long-term effort to support New Zealand farmers to instigate practical farm management strategies that improve sustainability and ecological resilience.

A key factor in the degree of implementation and success of riparian management by farmers and land managers is the extent to which tangible benefits are achieved at the farm scale. In this study, we examined whether different farm and waterway management actions on sheep/beef and dairy farms resulted in detectible changes in water quality and ecosystem functioning at the farm scale. More farmers may invest time or money into stream care if they can detect real improvements in stream health within the reach of streams on their own property. Immediate and local responses in stream health to improved farm management will also allow farmers to experiment with alternative land management options to learn what is most cost effective.

The study had three specific aims:

- Provide baseline data on waterway quality and ecosystem function on sheep/beef and dairy farms, from which future trends in stream health can be determined;
- Identify the relative impacts of organic, integrated management, and conventional farming systems on water quality and aquatic ecosystem function on both sheep/beef and dairy farms; and
- Develop customized stream care management strategies for each participating farmer for incorporation into long-term whole-farm management plans.

We measured physical parameters, nutrient and sediment levels, and periphyton and aquatic macro-invertebrate communities at upstream and downstream sites in streams on 35 South

Island sheep/beef and 24 North Island dairy properties in summer 2005/2006. We used the Stream Health Monitoring and Assessment Kit (SHMAK), an assessment tool developed for use by farmers and landholders and additional measures to record relative changes in water quality and stream functioning at the farm scale.

Our findings were consistent with other studies and research demonstrating that water chemistry, community structure and ecosystem functioning are vastly different in agricultural waterways compared to those in unmodified habitats. We found evidence of different levels of pollution between farming sectors, with higher levels of nutrients (nitrate and nitrite, ammonium, dissolved reactive phosphorus, and total phosphorus) in waterways on dairy farms than on sheep/beef properties, while average concentrations of total organic carbon and organic and total sediment, and turbidity levels were higher on sheep/beef properties. However, we did not consistently find larger relative increases in nutrients or other pollutants between upstream and downstream sites on individual dairy farms than on sheep/beef farms in this study. Water quality and in-stream conditions changed and sometimes improved at the farm scale, and in some cases were significantly added to farm management action (such as effective stock exclusion) and nature and extent of riparian vegetation. Our findings suggest that there is potential for landholders to implement management actions that can result in protected or improved water quality within their own property boundaries, as well providing downstream benefits to other stakeholders.

The SHMAK assessment kit did not detect overall changes in stream health and functioning across individual farms, although we did record some changes in nutrient levels, sediment levels and other physical and biotic parameters across the study farms using the additional sampling techniques. We do not know at this stage if these changes are affecting ecosystem state and functioning and the SHMAK assessment is too insensitive to detect these subtle changes. Conversely, it is unclear if the additional measurements may be picking up trivial differences of no biological importance, and the SHMAK assessment may in fact be giving an accurate picture of overall stream health.

The conclusions from this study are only tentative, as they are based on only one survey per farm, and lack information on several potentially important variables. Additional sampling in summer 2006/2007 will allow us to better control for inter-annual variation in water quality measurements and to include additional variables in future analyses. Information on stock rotations and subsurface drainage systems are potentially important additional variables.

The results of this first survey have been relayed to each farmer in a report detailing: the state of waterways on their own farm; comparison data from other farms in the sector; and information on what factors or actions are affecting these results.

With the addition of data from the surveys in summer 2006/07, we will work with individual farmers to ensure that they have cost-effective and practical ways to manage waterways on their farms that provide environmental benefits. Suggested management actions may include stock exclusion for all or part of the year, riparian vegetation planting or management of existing vegetation, and modification of fertilizer application or stock management in areas adjacent to the waterway. However, it is crucial that any proposed actions do not threaten the long-term economic, social and environmental sustainability of the farming operation.

From this research we can offer the following recommendations:

- *Repeat stream monitoring in subsequent years to explore the causes of variability in stream health between individual farms, and to reveal underlying differences between these farming systems.*

- *Link stream health data to economic, social and farm management data generated by the ARGOS project so as to strengthen the explanatory power of the surveys.*

- *Provide feedback directly to farmers and assist with the development of management plans.* The results of this survey have identified important impacts to water quality at the farm scale and linked several key indicators to farm management practices. The ARGOS research design includes industry representatives who have personal relationships with each of our participating farm families and can provide direct and meaningful feedback and advice based on the findings of stream health monitoring. This process must begin immediately and continue for the duration of the research programme.

- *Continue to apply SHMAK protocols alongside ARGOS stream monitoring protocols* in order to assess the power of SHMAK as a tool and make recommendations on improvements to the SHMAK design.

Acknowledgements

The authors would like to thank John Harding from the University of Canterbury, and Gerry Closs, Sebastian Uhlmann and Mark Schallenberg from the University of Otago for advice on sampling design and protocols, and Debra Gauntlet from the University of Otago for analysis of laboratory samples. We are especially grateful to all the farmers involved who generously gave up their time to talk to us and allowed us onto their property.

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1 Introduction

One of the most important environmental, political and economic issues surrounding agriculture is the impact and interdependence of agricultural production on water resources. Agricultural systems are recognized as one of the primary sources of pollution and degradation in aquatic systems (for example see Muscutt, Harris et al. 1993; Belsky, Matzke et al. 1999; Line, Harman et al. 2000; Nakamura and Yamada 2003; Merseburger, Marti et al. 2005). The situation is similar in New Zealand (Scarsbrook and Halliday 1999), and a recent report identified water quality and supply in production landscapes as one of two key areas, along with increasing use and loads of nutrients, of environmental concern (Parliamentary Commissioner for the Environment 2004). Water quality in New Zealand is generally perceived to be high by international standards (for example Biggs, Kilroy et al. 1998), many lowland waterways are affected by agricultural, industrial and urban development (Ministry for the Environment 2001), and many fail to meet safe drinking water or bathing standards because of fecal contamination from farm animals, reduced water clarity and excessive nutrient levels (Parliamentary Commissioner for the Environment 2004).

Agricultural production requires fresh, clean water for stock watering, irrigation of crops and pasture, and for other aspects of the farming operation (such as dairy shed cleaning and vegetable washing). Such water use allows agriculture to earn in excess of 18 billion annually in New Zealand. This constitutes 40% the country's export earnings and approximately 6% of New Zealand's Gross Domestic Product (Parliamentary Commissioner for the Environment 2004).

The intensive agriculture required to produce such national benefits has potential to place severe stress on flowing freshwater and groundwater resources. A growing body of evidence links agricultural production with reduced water quality. Most point-sources of pollution associated with agriculture (such as direct input of dairy shed effluent or leaching from silage or offal pits) have been removed or controlled over the last 10 – 15 years (Ministry for the Environment 2001). Direct input of dairy shed effluent into waterways has now been almost completely diverted to land-based applications (Houlbrooke, Horne et al. 2004). Consequently, the majority of pollution entering waterways in agricultural systems now comes from non-point or 'diffuse' sources, such as leaching of excess nutrients from fertilizer and animal manure and increased sediment loads. The following section will examine these sources of pollution in more detail.

1.1 Non-point source pollution in agricultural systems

The three main non-point source pollution threats to flowing and groundwater in agricultural systems in New Zealand are (a) increased nutrient levels, particularly nitrogen and phosphorous; (b) microbial contamination; and (c) sediment loading. These pollutants may reduce diversity of plants and animals, threaten public health, and reduce productivity and animal health. Additional potential social effects include deterioration in aesthetic and recreation values of waterways.

Increased nutrient levels

Nitrogen and phosphorous are two of the main limiting nutrients for autotrophic growth and hence are the two most commonly applied elements in fertilizers (Statistics New Zealand 2003). Application rates of both nitrogen and phosphorous have been increasing in New Zealand over the last 50 years, but particularly in recent decades (MacLeod and Moller 2006). Over 300,000 tonnes of urea and 1,200,000 tonnes of phosphate were applied to production lands in 2002 (Statistics New Zealand 2003). The total application rates of urea and other nitrogen fertilizers increased by 160 % from 1996 levels, while those of phosphorous stayed fairly static (-7 % change). The large change in nitrogen application is driven by a shift in livestock sectors from biological nitrogen fixation (clover-based pastoral systems) to artificial sources. High levels of nitrogen and phosphorous in waterways can lead to excess algae and aquatic macrophyte growth (Cooper and Thomsen 1988; Quinn, Cooper et al. 1997) which may alter community structure and functioning (Thompson and Townsend 2004) and alter flow and flooding rates (Ministry for the Environment 2001). High levels of nitrogen and phosphorous can also make water unsafe for stock and human consumption (Ministry for the Environment 2001; Houlbrooke, Horne et al. 2004; Parliamentary Commissioner for the Environment 2004).

Microbial contamination

Animal feces contain high levels of bacteria and other microbes that pose serious human health risks once in water. Livestock, particularly cattle, are asymptomatic carries of a range of micro-organisms that can cause gastroenteritis in humans, noticeably *Giardia*, *Escherichia coli*, *Campylobacter* spp. and *Cryptosporidium* (Donnison and Ross 2003; Houlbrooke, Horne et al. 2004). Microbes enter waterways either via surface runoff or infiltration through the soil into groundwater (Aislabie, Smith et al. 2001). Input rates into flowing waters can also be rapid in areas with tile or mole drains (Donnison and Ross 2003), and high concentrations of microbes in waterways are a particular problem for the dairy industry (Parliamentary Commissioner for the Environment 2004).

Sediment loading

Increased rates of sediment input into streams is one of the most severe impacts of agriculture on water quality in New Zealand (Sinner 1992; Ministry for the Environment 2001; Parliamentary Commissioner for the Environment 2004). While historical land clearing would have most likely increased sediment loadings in New Zealand waterways, the current threats come from direct bank erosion by stock (Ministry for the Environment 2001; Canterbury 2005) and water and wind erosion of bare soils, particularly in cropping areas (Ministry for the Environment 1997). Increased sediment levels in waterways can reduce water clarity and primary production by reducing light levels and smothering or scouring periphyton and macrophytes (Davies-Colley, Hickley et al. 1992; Nakamura and Yamada 2003; Francoeur and Biggs 2006). Sediment also covers substrate and fills interstitial spaces, thereby reducing habitat and food availability for invertebrates (Quinn, Davies-Colley et al. 1992; Quinn, Cooper et al. 1997) and fish (Rabeni and Smale 1995; Wood and Armitage 1997; Zimmerman, Vondracek et al. 2003; St-Hilaire, Caissie et al. 2005), additionally sediment inputs are the major source of phosphorous enrichment in waterways. Phosphorous readily binds to soil particles (Kalff 2002). It has been estimated that from 50 % (Vaithiyanathan and Correll 1992; Cooke and Prepas 1998) to more than 80 % (Kalff 2002) of phosphorous enters streams bound to sediments, with only ~15 % entering the stream in a dissolved form.

In the following section we explore the range of management options available to maximize protection and enhancement of water quality, as well as reasons why farmers are not using these management strategies.

1.2 Options for management and mitigation of agricultural impacts on waterways

Agricultural impacts on aquatic ecosystems occur at very different scales; ranging from the presence of individual stock at a stock crossing or an unprotected stretch of a waterway, to excessive nutrient loading as a result of inappropriate fertilizer or manure management at the farm scale, to whole catchment effects of land management practices (for example catchment-wide clearing of forest or changes in production systems). While existing theoretical and practical knowledge offer mechanisms for managing and reducing impacts on water quality and aquatic ecosystem functioning, they must target the appropriate scale in order to be effective. For example, fencing of waterways to reduce direct stock access can result in reduced sediment loading, and higher water clarity and lower levels of nutrients and microbes entering the waterway (Owens, Edwards et al. 1996; Line, Harman et al. 2000; Byers, Cabrera et al. 2005). Similarly, maintenance of appropriate grassy buffer strips can significantly reduce inputs of sediment and phosphorous (Robinson, Ghaffarzadeh et al. 1996; Sovell, Vondracek et al. 2000; Hook 2003; Wigington, Griffith et al. 2003; Jobin, Belanger et al. 2004), while integrated land use planning at the catchment scale can protect water quality and clarity (for example Environment Bay of Plenty 2000; Environment Waikato 2005).

Farmers are becoming increasingly aware of the impacts that their land management practices have on aquatic systems and many are changing their management accordingly. However, there are several social and economic reasons why many farmers and land managers have yet to make any changes. Retirement fencing and riparian tree planting are seen as removing land from production and involving capital outlay for no financial return (Rhodes, Leland et al. 2002). This has been a particularly important penalty in recent years when farm profits are falling in many sectors (Ministry for the Environment 2001). There may also be a perception that the landholder will receive no direct benefit from mitigation actions themselves, but rather their actions (and financial outlay) will benefit other users or communities downstream of their farm run-off. Some farmers may be understandably reluctant to carry costs of environmental protection for public good.

Another contributing factor to the inaction in implementing on-farm waterway management is a lack of understanding about the impact of farming activities, such as the source of farm-generated contaminants and how they enter streams, rivers and drains (Ministry for the Environment 2001). As the MfE (2001) report *Managing waterways on farms: a guide to sustainable water and riparian management in rural New Zealand* states:

"Without that understanding, landowners and technicians are neither motivated nor equipped to apply appropriate management techniques that are necessary to make a difference. Where the knowledge does exist, extraordinary progress has been made by individual landowners, often at little or no net cost to the farming operation. Increasingly, we see that more sustainable land and water management can contribute to, rather than contradict, increased farm profitability".

In general, both policy makers and land managers are not in favour of central- or local-government derived compulsory waterway management strategies. Voluntary implementation of best management practices are preferred by farmers and policy makers alike (Kline, Alig et al. 2000; Rhodes, Leland et al. 2002). Best management strategies, such as the dairy sector's 'Clean Streams Accord' (Group, Zealand et al. 2003), which are nevertheless aligned to regulatory requirements (specifically the Resource Management Act 1991), are the primary mechanism for ensuring appropriate waterway management in agricultural systems in New

Zealand. Imposition of stocking limits or even exclusion of dairy farming altogether is now being discussed for important and degraded catchments such as Taupo and the Rotorua Lakes.

New Zealand is unique in the world in relying very strongly on market incentive schemes such as Organic and Integrated Management (IM) accreditation to ‘green’ its agriculture (Campbell and Lyons 2003; Campbell 2004). Organic management strategies claim significant potential to increase broad biodiversity values and enhance environmental performance. However, organic farming requires high levels of management skill to maintain satisfactory levels of production and financial return. Organic farms are still uncommon and may remain so. IM farms are rapidly becoming more common and potentially offer an intermediate strategy between organic and conventional growing, by aiming to apply minimal farm inputs at optimum places and times. Overseas food market chains and their customers are increasingly demanding that food and fibre purchased from New Zealand farms is produced in an ecologically sustainable way; i.e. one that supports other plants and animals in the farm landscape as well as the ‘agricultural biodiversity’ that directly assists production. It is important to discover whether farm accreditation schemes like IM and organic certification result in improved stream health. If so, accreditation may provide valuable incentives and economic returns to farmers that instigate stream care strategies.

In this study, the Agricultural Research Group on Sustainability (ARGOS) worked with individual landholders to identify the effects of farm management practices on water quality and waterway functioning at the farm scale. Our aim was to provide information to landholders on impacts of their farming operations on their own waterway and information and examples of how they can increase waterway quality and functioning within their own farm boundaries and for downstream stakeholders. This is the first step in a long-term effort by ARGOS to support New Zealand farmers to instigate practical farm management strategies that improve sustainability and ecological resilience.

We had three specific objectives:

1. Provide baseline data on waterway quality and ecosystem function on sheep/beef and dairy farms using monitoring techniques designed to be used by individual landholders (the Stream Health Monitoring and Assessment Kit; SHMAK), and additional more detailed monitoring techniques to record water physio-chemical measures, nutrient loadings, and periphyton and invertebrate and fish communities.

2. Identify the relative impacts of organic, IM, and conventional farming systems on water quality and aquatic ecosystem function on both sheep/beef and dairy farms.

3. Use information on waterways from individual farms to identify threats to and opportunities for increasing water quality at the farm scale; broaden knowledge of waterway management, and identify customized stream care management strategies for each participating farmer. The long-term aim is to incorporate stream care actions into whole-farm management plans.

The current report primarily addresses the first two aims of the project. The third aim, to develop individual stream care management strategies with individual farmers, is an ongoing process. It will involve a dialogue between researchers and landholders, where scientific information on the state and functioning of waterways on each farm is discussed with the landholder. Opportunities for protecting or enhancing the environmental sustainability of the waterway can then be combined with the social, economic and environmental visions of the farmer. Similarly, our baseline measures of stream health (Objective 1) will have more value once ongoing annual or biannual surveys are completed to allow trend detection.

2 Methods

Stream health[1] and riparian assessments were conducted in the Austral summer 2005/2006 on 35 ARGOS South Island Sheep and Beef properties (Figure 1) and 24 North Island dairy farms (Figure 2) that had stream channels within the property boundaries. Within each sector (sheep/beef and dairy) farms are arranged in twelve 'clusters'; triplets (in the case of sheep/beef) or pairs (for dairy) of closely located farms that are matched for geographic location, climate, rainfall and geology. Each property in a cluster has a different farm management system and therefore belong to a different 'panel' in ARGOS's quasi-experimental design. In sheep/beef these are certified organic production ('Organic'), integrated management ('IM') where inputs and management options are aligned with market-led audit systems, and conventional ('Conventional') which comprises the standard 'business as usual' farm management. For dairy, the two panels are properties entering organic conversion ('Organic') and conventional management ('Conventional'). Sheep/beef farms were surveyed between 29/11/2005 and 25/01/2006; and dairy farms were surveyed between 11/02/2006 and 11/03/2006.

The main objective of the study was to isolate the effects of farm management on stream health and functioning <u>at the farm scale</u>. Consequently, two study sites were selected on each farm; an upstream site where the stream either entered the property, or at the source if it arose within the farm boundaries; and a downstream site where the stream left the property.

Potential candidate survey sites were initially identified by consulting existing farm maps of each property, and talking to ARGOS Field Managers and staff with previous experience of the properties. Individual waterways (streams and/or irrigation raceways) were selected for this survey and as part of the longer-term ARGOS monitoring program to be as representative of the waterways on the farm and on the other farms in the cluster. Selected waterways were the longest reach on the farm that was not intersected by tributaries with a source outside the property. If possible, we surveyed a reach that was previously surveyed on the sheep/beef farms, in an earlier study in summer 2004/2005 (Blackwell, Rate et al. 2005).

Upon arrival at the farm, the potential survey sites were discussed with the farmer to check suitability and any access issues, and then inspected. On each selected stream reach, an upstream and downstream monitoring site that met the SHMAK kit sample-site criteria was identified. Such sites needed to encompass a ten-metre length of stream with a ten metre wide riparian strip along each the true right and true left banks. It had to be straight or only slightly curved and set up in runs (sections where the stream flow is steady and the surface is unbroken; (Biggs, Kilroy et al. 1998).

[1] We follow the definition of Karr, J. R. (1999). Defining and measuring river health. *Freshwater Biology* **41**: 221-234., who defines stream health as " the ability to sustainably supply the goods and services of both human and non-human residents (stakeholders).

2.1 Stream health assessments

A comprehensive assessment of stream functioning and health was made at each site, using a combination of the SHMAK kit assessment protocol and additional water quality and riparian habitat measurements. The combined approach was taken to allow the comparison of the indices from the SHMAK protocol and more standard analytical techniques in assessing stream status and functioning.

SHMAK monitoring protocols

'Level 2' monitoring was conducted following the protocols defined in the SHMAK handbook (Biggs, Kilroy et al. 1998). The SHMAK kit has been developed to allow farmers, landholders and regulatory authorities to gain an indication of the health of a waterway, and therefore uses a range of simple, easily understood, ecologically-based indices developed for New Zealand waterways (Biggs, Kilroy et al. 1998). The overall assessment of stream health in the SHMAK kit combines information on aquatic plants and animals (as indicators of in-stream conditions), measurements of the physical habitat in the stream and riparian zone, and knowledge of surrounding land use and farm management, to produce a relative index of stream health (from "very poor" to "excellent") for a given stream and stream type. The protocols are explained in detail in Biggs *et al*. 1998, and will only be outlined here.

At each survey site, a ten-metre length of rope was stretched along the bank to mark the survey area, and a GPS location was taken at the center of the survey site with a Garmin eTrex hand-held GPS unit (Garmin International Incorporated, Olathe, Kansas). Two photographs were taken with a Nikon Coolpix 4300 camera with a 35mm lens; one looking upstream from the downstream end of the survey area, and the second looking downstream from the upstream end of the survey area.

The physical characteristics of the site were recorded (Table 1), including the average stream width and depth, water velocity, water temperature, pH, conductivity, and water clarity (using a 1 m long clarity tube). The composition of the stream bed including any sediment deposits, and the riparian vegetation were recorded, as was any information on the management of the stream channel, riparian area and surroundings. In a SHMAK assessment carried out by a landholder, recent flow conditions are noted as are any events that could affect the accuracy of the assessment. This was not always possible for our survey team during a one-off visit, although information on recent conditions was obtained from landholders where possible.

When assessing the stream bed and riparian habitat, weightings are given to different substrate or vegetation types, based on their ecological functioning and contributions to stream health. In the streambed assessment for example, silty/muddy substrates (highly mobile and poor habitat for macrophytes and stream invertebrates) are given a -20 weighting. Gravelly substrates, which provide habitat for invertebrates in stable flows but move easily at higher water velocity are given a weighting of 0. Large cobbles (stones 15 – 25 cm across – stable and good habitat for insects and fish) are given a weighting of +20. Similarly, the riparian cover on each bank is scored and averaged for the site, with weightings given to different cover types. For example, pasture grasses and herbaceous plants have low structural complexity and shallow roots, so neither are very effective at trapping sediment or filtering nutrients. They are given a weighting of -10. Native trees provide shading and nutrient input through leaf fall, are good at filtering nutrients in sub-surface flows. They are given a weighting of +10. The presence and extent of stream deposits are noted as an indication of recent disturbances or sediment inputs into the stream.

Stream macro-invertebrates are assessed at each site, using a modified version of the Macroinvertebrate Community Index (MCI Stark 1985). The identity (to 'morpho-species' level) and abundance of all invertebrates was assessed on ten 6 – 12 cm cobbles. For sandy or silty streams, ten samples were collected in a 10 cm diameter hand-held sieve. Different species are given weightings in the SHMAK assessment, based on their habitat requirements and tolerance to degraded conditions. The MCI was originally developed for stony streams in Taranaki, and has been modified in the SHMAK to allow comparisons between different stream types with quite different underlying habitats (e.g. naturally sandy bottomed streams and stony streams).

Assessments of periphyton (primarily algae, with small amounts of bacteria and fungi) levels in the stream were also made. Periphyton can be a useful indicator of overall conditions in the stream, because it is immobile and so is a long term integrator of water quality and flow conditions, and is easy to collect and identify (Biggs *et al*. 1998). The average percentage cover of different periphyton types (morphotaxa) on ten 6 – 12 cm cobbles (or ten samples collected in a 10 cm sieve) was recorded. As with the other SHMAK assessments, a weighting was given to each periphyton type, with thin mats (indicating good water quality and good invertebrate populations) given scores of 7 – 10, and thick mats and long filamentous algae given low scores of 1 - 4 (indicating low flows and high nutrient and light levels).

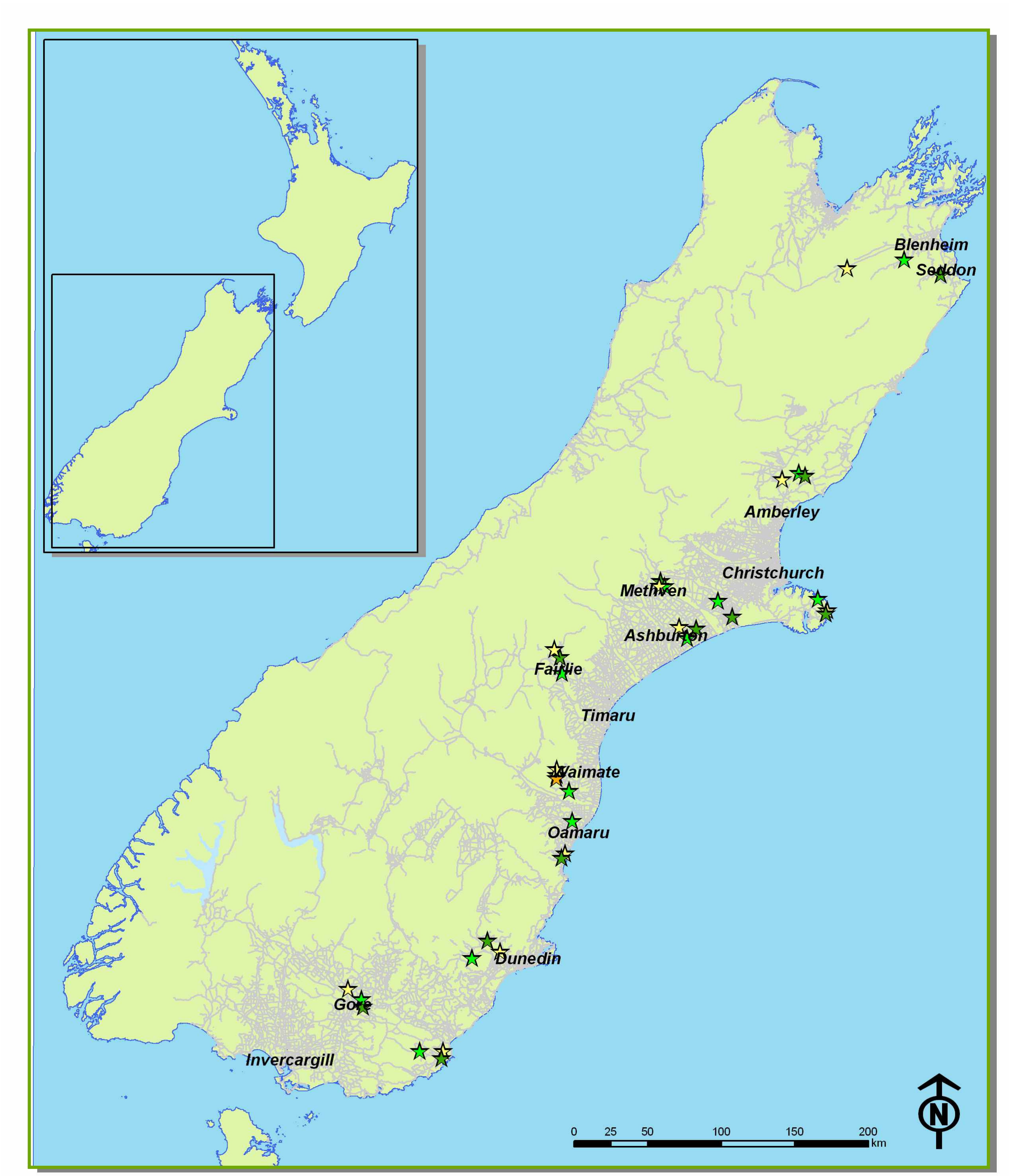

Figure 1: Locations of ARGOS sheep/beef properties surveyed in this study. Each 'cluster' of properties is indicated by three stars, where one property employs Organic management practices, one employs integrated management practices (IM) and one employs conventional management practices. One property in the Waimate cluster was undergoing organic conversion, and one has been sold and therefore left the ARGOS programme. The latter two properties were not included in the analyses presented in this report.

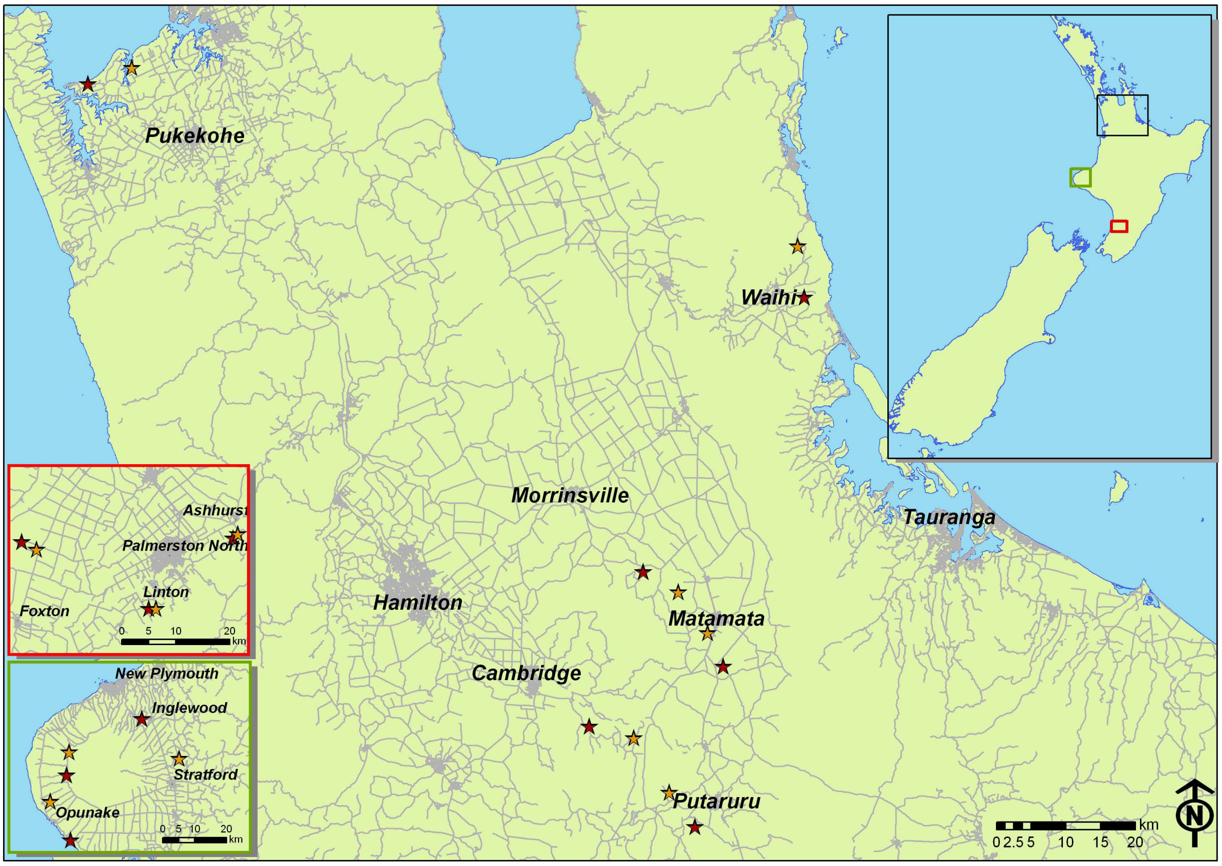

Figure 2: Locations of ARGOS dairy farms surveyed in this study. Each 'cluster' of properties is indicated by a pair of stars, where one of the properties is undergoing organic conversion and the other is applies conventional farm management practices.

Table 1: Parameters recorded in the Stream Health Monitoring and Assessment Kit (SHMAK).

Parameter	Units	Method of recording
Stream width	Metres	Average of width at bottom, middle and top of survey site
Stream depth	Metres	Average of depth at true left bank, centre, and true right bank at the bottom, middle and top of the study site
Flow velocity	Metres/second	Average time for a floating object to travel the length of the survey site (three replicates)
Water temperature	Degrees centigrade	Bulb thermometer temperature of water in the middle of the channel at the upstream end
pH	$-\log_{10}(H^+$ ion concentration)	Merck Neutralit pH strips in a container of stream water for 10 minutes
Water conductivity	Microseimens cm^{-1}	EUTECH Cybernetics TDScan 3 hand-held conductivity meter in a container of stream water
Water clarity	Detection distance (metres)	Distance at which a black disc can be detected along a 1-metre length clear acrylic tube filled with stream water (three replicates)
Stream bed	Index between -20 - +20	Percentage cover of different substrate types, weighted by their ecological function (see text)
Riparian vegetation	Index between -10 - +10	Percentage cover of different vegetation types, weighted by their ecological function (see text)
Deposits	Index between -10 - +10	Qualitative assessment of the extent of substrate covered by sediment and other deposits
Invertebrates	Index between 0 - 10	Abundance of different stream invertebrates weighted by their ecological requirements and sensitivity to stream modification
Periphyton	Index between 0 - 10	Percentage cover of different algae taxa weighted by their ecological requirements and sensitivity to enrichment

Additional measurements collected for SHMAK validation

In addition to the information collected as part of the SHMAK assessment, additional information was also collected on water clarity and quality and stream biota. A YSI 556 MPS (Multi Probe System) was used to record water temperature (degrees centigrade), dissolved oxygen (mg/L), conductivity (Microseimens cm^{-1}), salinity (parts per million), pH and total dissolved solids. At each site, the YSI 556 was placed in the stream and allowed to stabilize for five to ten minutes before readings were taken.

The following nutrients were also analysed for each site:

Ammonia (NH3 ug/L): Water samples were collected in the main flow of the waterway at upstream (undisturbed) end of each site[2]. The automated procedure for the determination of Ammonia is based on the modified Berthelot reaction: ammonia is chlorinated to monochloramine, which reacts with phenol. After oxidation and oxidative coupling a green coloured complex is formed. The reaction is catalysed by nitroprusside; sodium hypochlorite is used for chlorine donation. The absorption of the complex is measured at 630nm.

Total nitrogen (TN ug/L) and total phosphate (TP ug/L): Water samples were collected in the main flow of the waterway at upstream (undisturbed) end of each site. Samples were collected in 100 ml acid washed Astroline bottles and kept refrigerated or on ice for up to six weeks before freezing. Samples were analysed using a SKALAR TN and TP autoanalyser.

Dissolved Reactive Phosphate (DRP ug/L): Water samples were collected in the main flow of the waterway at upstream (undisturbed) end of each site. Samples were filtered through Waterman 20mm glass fibre filters into a 100 ml acid washed Astroline bottles. The automated procedure for the determination of Phosphate is based on the following reactions: (a) ammonium molybdate and potassium antimony tartrate react in an acidic medium with diluted solutions of phosphate to form an antimony-phospho-molybdate complex; (b) this complex is reduced to an intensely blue-coloured complex by ascorbic acid; and (c) the absorption of the complex is measured at 880nm.

Nitrate and Nitrite (NO3 + NO2 ug/L): Water samples were collected in the main flow of the waterway at upstream (undisturbed) end of each site. Samples were filtered through Waterman 20mm glass fibre filters into a 100 ml acid washed Astroline bottles. The automated procedure for the determination of Nitrate and Nitrite is based on the cadmium reduction method. The sample is passed through a column containing granulated copper-cadmium to reduce the nitrate to nitrite. The nitrite (originally present plus reduced nitrate) is determined by diazotizing with sulfanilamide and coupling with α-naphthylehylenediamine dihydrochloride to form a highly coloured azo dye which is measured at 540 nm.

Total organic carbon (TOC): Water samples were collected in the main flow of the waterway at upstream (undisturbed) end of each site. Samples were filtered through Waterman 20mm glass fibre filters into two 20 ml glass bottles, placed on ice immediately and frozen within eight hours of collection.[3] Frozen samples were thawed and placed in a Shimadzu TOC-V CSH Total Organic Carbon Analyser which acidifies the sample to pH 2-3 then bubbles sparge gas through the sample to eliminate the inorganic carbon (IC) component. The remaining total carbon (TC) is measured to determine total organic carbon, and the result is generally referred to as 'Total Organic Carbon' (TOC). The Shimadzu TOC-V refers to the result as NPOC. NPOC stands for Non-Purgable Organic Carbon and refers to organic carbon that is present in a sample in a non-volatile form.

Turbidity: Water samples were collected in the main flow of the waterway at upstream (undisturbed) end of each site. Samples were re-agitated for 15 seconds and analysed in a calibrated HACH Model 2100A Turbidimeter.

[2] For all assays described here, except #5, #8 and #9, samples were collected in 100 ml acid washed Astroline bottles and kept refrigerated or on ice for up to six weeks before freezing (more rapid processing of these latter samples was required).

[3] Some thawing (5% to 100% of the volume) occurred in samples during transport on two occasions during sheep/beef surveys and on two occasions during dairy surveys.

Organic stream deposits: Suspended sediment samples were collected by agitating the streambed within a 5 litre bucket with the bottom removed placed on the stream bottom with the lip of the bucket above the water's surface. A plastic kitchen-variety scrubbing brush was used to agitate the streambed for 30 seconds, and water and sediment collected by dipping a 100 ml pink top pottle (Labserv) inside the bucket with sediment still in an agitated state. In the laboratory, the sample was re-agitated for 15 seconds and 15 ml drawn into a 2mm aperture pipette 5ml at a time and passed through a pre-ashed (2 hrs at 400˚C) filter paper (Whatman GFC 47 mm), dried at 105˚C for 24 hours, and weighted to get total sediment figure. The sediment was then combusted at 400˚C for 2 hours, re-wetted, dried at 105˚C for 24 hours, cooled in a desiccator for 30 minutes then weighted to determine the organic portion.

Faecal coliform: Coliforms were measured on dairy farms only. Water samples were collected in bottles supplied by Hill Laboratories in Hamilton, placed on ice immediately and sent back to the laboratory within 24 hours. Membrane Filtration with resuscitation, count on mFC Agar at 44.5 °C after 24 hours. Analysed at BioTest Laboratories. APHA 9222 D, 20th ed. 1998. Detection limit to 1 cfu/100 mL.

Escherichia coli: Escherichia coli was measured on dairy farms only. Water samples were collected in bottles supplied by Hill Laboratories in Hamilton, placed on ice immediately and sent back to the laboratory within 24 hours. Confirmation of colonies ex mFC by fluorescence of transferred membrane on NA-MUG after 4 hours at 35°C. Analysed at BioTest Laboratories. APHA 9222 G, 20th ed. 1998. Detection limit to 1 cfu/100 mL.

Additional invertebrate samples were collected to allow more detailed assessment of the macroinvertebrate community present at each site. The use of a Surber net provides a quantitative method to study stream invertebrates that complements the qualitative substrate sampling technique used by the SHMAK kit. The Surber net's horizontal frame was placed on the streambed and the substrate within the frame disturbed with a plastic handled kitchen scrub brush and screwdriver for two minutes. Dislodged invertebrates were swept downstream by the current into the 60cm long net, transferred to plastic pottles, preserved in 5% Ethanol and stored at room temperature. Three samples were collected at each SHMAK site from random locations along the 10m stream reach.

Riparian habitat management surveys

In addition to the riparian habitat assessments conducted at each SHMAK sampling site, a further eight sites were identified for riparian assessments along each selected stream reach. Each site encompassed a 10 metre length of stream and a 10 metre wide riparian strip along each the true right and true left banks. One riparian habitat assessment was conducted at each the upstream and downstream monitoring sites, and at the eight additional assessments spaced at equal intervals along the stream reach (between the upstream and downstream monitoring sites). The same SHMAK sampling protocol was used at the additional sites, giving a total of ten riparian survey sites per farm.

At each of the eight additional sites, the location was recorded with a hand-held GPS unit and a photo was taken looking upstream from the downstream end of the survey site. The physical dimensions of the reach (average width and depth), stream bed and riparian vegetation and any management features were recorded as for the upstream and downstream SHMAK assessments.

Any man-made landforms, such as bridges, culverts, fences, and/or structures in the stream channel or riparian strip that were encountered were mapped along the entire stream reach. At each landform, the location was recorded with a GPS, a photograph was taken, and a brief description was made (including whether the feature formed an obstruction to flow or fish movement).

2.2 Statistical analysis

Differences between clusters of farms, management systems ('Panels') and farm sectors were investigated using one-way randomized block analysis of variance in GENSTAT Version 8 (VSN International Ltd), where the different clusters were the randomized blocks and Panels and sectors were the fixed factors of interest. This model is non-additive (that is, it assumes interactions between Panels and Clusters), and consequently no significance tests of between-block differences are possible as there is no mean squares estimate that has the same expected value as the residual mean squares when the null hypothesis is true (Quinn and Keough 2002). However, an estimate of the contribution to the model made by the block structure (Clusters) can be gained by examining the variance components of the block and treatment (Panel) model strata. In some cases, missing values for variables of interest required that the analysis be modified by (a) removing the blocking by cluster when comparing treatments (potentially resulting in a larger residual mean squares), and (b) by applying a randomized blocked model to the subset of blocks (clusters) where all data where available (reducing the degrees of freedom). In such cases, both models were run and the results compared to gain an understanding of the underlying patterns. Any pairwise differences were tested *post hoc* using Tukey's Honestly Significant Difference (HSD) test.

Percentage change in each parameter from the upstream to the downstream survey site on individual farms was used as the primary response variable of interest. The use of percentage change allowed any upstream impacts that may have affected the waterway before it reached the ARGOS farm to be factored out. Average values for each parameter on each farm were also examined to allow additional comparison.

Water clarity and nutrient levels

Principal Components Analysis (PCA) was used to look for overall differences in percentage changes of water clarity and nutrient levels on individual farms. A PCA analysis seeks to find orthogonal (un-correlated) indices, termed principal components, based on p variables X_1, X_2, … X_p of interest. Each principal component is then a multivariate summary of the primary trends in the data. For the water clarity analysis, the variables considered for each farm were the percentage change in clarity tube reading, the percentage change in organic sediment, and the percentage change in total sediment. For the nutrient analysis, the variables considered for each farm were the percentage change in dissolved reactive phosphorous (DRP), ammonium (NH_4^+), nitrate and nitrite (NO_2 + NO_3), total organic carbon (TOC), and total phosphorous (TP). Total nitrogen was estimated but was not used in the analysis as there were inconsistencies in the laboratory results, with the estimates of NH_4^+ and NO_2 + NO_3, often summing to greater concentrations than the estimates of total nitrogen. A correlation matrix (where all variables are standardized to have zero means and unit variance) rather than covariance matrix was used as variables used in the analyses were measured using different scales, and relative differences between farms were of primary interest. The water clarity and nutrient PCAs were performed separately for the sheep/beef and dairy sectors.

Macro-invertebrate and periphyton community composition

Overall macro-invertebrate and periphyton community composition and differences between clusters and panels for the sheep/beef and dairy sector were examined using two related multivariate techniques: discriminant function analysis (DFA) and multivariate analysis of variance (MANOVA). A DFA analysis is a classification technique used when there are multiple observations from a single pre-determined unit (in this case, the different macroinvertebrates or periphyton morphotaxa recorded at an upstream or downstream sampling site on a farm). Linear combinations of these variables were generated that maximize the probability of correctly assigning an individual site to it's own group, or that allow the classification of new sites (Quinn and Keough 2002). A MANOVA is a related technique that tests for differences between pre-determined groups in the overall mean of all measured variables considered simultaneously. In this study, MANOVA was used to test if there were overall differences in the abundances of the different macro-invertebrates and periphyton taxa recorded at each site-category (upstream and downstream sites on farms in each panel). There were six site-category combinations in sheep/beef (Organic-upstream, Organic-downstream, IM-upstream, IM-downstream, Conventional-upstream and Conventional-downstream); and four combinations in dairy (Organic-upstream, Organic-downstream, Conventional-upstream and Conventional-downstream). The differences in invertebrate community composition were also tested between panels in each sector (upstream and downstream sites pooled), and between upstream and down stream sites (Panels pooled), and for panel by site interaction in the dairy sector only, using the MANOVA randomized block option in GENSTAT Version 8. The site and site by panel comparisons could not be performed in the sheep/beef sector as the design was not balanced in this sector[4]. The analysis produces test statistics based on the variance of the matrix used, for which the sampling distribution is poorly understood, but is converted to an approximate χ^2 or F-ratio statistic (Quinn and Keough 2002). Pillai's trace, which is an estimate of the variance between groups, is considered to be the most robust estimate when there are more than two groups of interest (Johnson and Field 1993), and is reported here along with an approximate χ^2 distribution. Only invertebrate morphospecies and periphyton morphotaxa that were present at more than 5 sites were used in the analyses.

Predicting farm scale changes in water quality

Generalized linear models (GLM's) were used for the model selection, using the 'all subsets' option in GENSTAT Version 8 to link stream quality measures to farm land use predictions. GLM's assume linear or monotonically increasing or decreasing trends in the response variable and allow the modeling of different error distributions (e.g. normal, poisson or binomial). *Post-hoc* exploratory model selection can suffer from a number of limitations, particularly when large numbers of predictor variables are checked, and when forwards, backwards or stepwise regression approaches are used. Such analyses can suffer from increased probabilities of type I statistical errors, they are based on arbitrary statistical rules regarding including or excluding variables, and they can be affected by colinearity so that important predictor variables may be left out (James and McCulloch 1990; Chaterjee and Price 1991; Quinn and Keough 2002). In the

[4] The same number of levels are required for each factor; in sheep/beef there were three levels for panel (organic, IM and conventional) and two for site (up- and down-stream).

current report, an all subsets approach was employed, with the most parsimonious model selected using Akiake's Information Criterion (AIC), which selects the model that explains the most variance with the fewest parameters.

Separate models were constructed for the dairy and sheep/beef sectors to predict the percentage change in both individual water clarity and nutrient levels, and the multivariate measures of clarity and nutrient change using the first two principal components from the PCA analyses. A subset of the measured variables was selected as predictor variables for the analyses (Table 2). The selected variables were chosen as indicators of habitat features or farm management practices that are generally known to affect water quality and stream health, and are amenable to modification by farmers if required. Individual models were built to predict percentage change in DRP, TP, NH_4^+, NO_2 + NO_3, TOC, organic sediment, total sediment, clarity tube reading, and overall water clarity (Water clarity PCA Axis 1 and 2) and nutrient levels (Nutrient PCA Axis 1 and2).

Table 2*:* Variables used in the predictive model selection process to identify links between stream health and farm management. All-subsets generalized linear models were used to build the models and Akiake's Information Criterion was used to select the most parsimonious model. Models were built separately for each response variable (see text) and the process was conducted separately for the dairy and sheep/beef farms.

Predictor variable	Variable levels	Explanation
Panel	Dairy: Organic and Conventional Sheep/beef Organic, IM and Conventional	Alternative farming systems may have different levels of inputs or stock or farm management practices that could affect water quality
Bank vegetation	Index from -10 (little or sparse vegetation) to +10 (extensive cover of woody vegetation and a dense understory)	A weighted average riparian vegetation cover score for each farm. Weightings based on ecological function (see text)
Fencing	Index from 0 (no fencing) to 10 (both sides fenced for whole length of waterway)	Effective fences can prevent direct stock access into the stream bed and can prevent grazing of riparian vegetation, allowing denser ground cover to develop that is more effective at stopping sediment and nutrient inputs.
Stock access	Index from 0 (free stock access to whole waterway) to 10 (effective fencing or barriers that prevent stock access)	Stock in the waterway can lead to increased bank erosion and sediment loading and increased nutrient levels through direct inputs of waste.
Stream bed	Index from -20 (unstable silty/sandy or man-made surfaces) to +20 (stable bed of cobbles and boulders)	The stream bed type can partially determine what plants and animals can persist in the stream, as well as playing a role in sediment deposition and nutrient transport and retention rates.
Additional vegetation predictors		
Vegetation PCA Axis 1	PCA Axis scores (Relative ranking)	A multivariate indicator of overall vegetation cover at a site, but without the weightings inherent in the SHMAK Bank vegetation index
Vegetation PCA Axis 2	PCA Axis scores (Relative ranking)	A second multivariate indicator (uncorrelated with PCA Axis 1) of overall vegetation cover at a site, but without the weightings inherent in the SHMAK Bank vegetation index
Bare ground	Average percentage cover in the riparian strip	Bare ground can increase infiltration rates of rainwater, sediment and nutrients into waterways
Pasture	Average percentage cover in the riparian strip	Short pasture offers little barrier to sediment transport into waterways, while the shallow root zone is not a very effective nutrient filter. Longer ungrazed pasture can act as an effective sediment trap.

Predictor variable	Variable levels	Explanation
Scrub	Average percentage cover in the riparian strip	Scrub (low woody vegetation) can offer a good barrier to sediment and nutrients, provide some shade and habitat for terrestrial species
Trees	Average percentage cover in the riparian strip	Trees can provide good nutrient filtering through the root zone, shading of the channel, an energy input from leaf-fall, and habitat for terrestrial species.
Tussock	Average percentage cover in the riparian strip	Tussock (and long rank grass) can act as effective sediment traps, reducing sediment and associated nutrient or microbe inputs.

3 Results

Of the 35 sheep/beef properties in the ARGOS program, all farms had natural or man-made waterways present on the property Of these properties, 26 had flowing water at the time of the farm visit and were included in the analysis. Of the 24 dairy properties in the program, 18 had waterways present on the property. Of these 18 properties, 15 had flowing water at the time of the farm visit and were included in the analysis.

3.1 Basic parameters by cluster and panel

Average values in sheep/beef farms

Average values for the measured parameters on ARGOS sheep/beef farms are given for each cluster in Table 3. Waterways tended to be narrow and shallow, with average temperatures that ranged from just under 9℃ to over 19℃. The riparian habitat on most farms was predominantly grazed pasture (as indicated by the negative SHMAK bank vegetation scores, and none of the surveyed reaches had the riparian zone completely fenced on both banks. Concentrations of NH_4^+ and NO_2 + NO_3 (grand means of 44.91 ug/L and 610.41 ug/L respectively) were higher than concentrations of DRP (grand mean of 14.12 ug/L), although levels of nutrients (and most other variables) were highly variable between farms and clusters (%CV's of over 100% in a number of cases; Table 3). Due to the large and randomly distributed number of missing data points, the differences between clusters were not tested statistically.

Differences in average values between panels are shown in Table 4. Waterways on Organic, IM and Conventional sheep/beef farms did not differ significantly in width, depth, temperature, pH, water velocity, or clarity, although again, there was a high degree of variation between the farms within any one panel (some %CV's of over 200%). Nutrient levels differed between panels, although the only variables for which significant differences between panels existed were total organic carbon, with concentrations in water on Organic farms significantly higher than either IM or Conventional farms, and turbidity levels, where Conventional farms had significantly higher levels than either Organic or IM (Table 4)

Average values in dairy farms

Average values for the measured parameters on ARGOS dairy farms are shown in Table 5. As with the sheep/beef farms, waterways on ARGOS dairy farms were fairly narrow, shallow and slow moving. The predominant vegetation cover was pasture, contributing to the predominantly negative SHMAK bank vegetation scores. Fencing was more common on waterways on dairy farms, with 5 of the 19 (26 %) survey sites being completely fenced on both sides, although 9 sites (47 %) had no fencing at all.

Levels of NO_2 + NO_3 (grand mean of 1288.53 ug/L) were the highest of the measured nutrients, although unlike the sheep/beef farms, levels of NH_4^+ and DRP were similar to each other (grand means of 215.3 ug/L and 225.06 ug/L respectively; Table 5).

Differences in average values between panels are shown in Table 6. Waterways on Organic conversion farms tended to be wider, shallower, warmer and faster flowing than those on Conventional dairy farms. Organic conversion farms also tended to have higher levels of NO_2 +

NO_3 and DRP in the waterway, and significantly higher levels of organic sediment ($F_{1,13}$ = 10.02, P = 0.007). Conventional dairy farms tended to have better water clarity tube readings, higher dissolved oxygen levels, NH_4^+ concentrations and conductivities, and lower sediment loads.

Comparison between sectors of average values

The average values for each parameter in dairy farms and sheep/beef farms in the current study are shown in Table 7. Waterways on dairy farms were significantly deeper and warmer than water ways on sheep/beef farms, although there were no other significant differences in the physical properties of waterways in the two sectors. Concentrations of all measured nutrients, with the exception of TOC, were higher in waterways on dairy farms than on sheep/beef farms, although the highly variable nature of the data means that none of these differences are significant. Average water velocity was higher on sheep/beef farms, and total sediment was higher, and clarity tube readings lower, on sheep/beef than on dairy farms. Bank vegetation scores, stream bed scores and invertebrate and periphyton scores were all higher on sheep/beef farms, but again, these differences were not significant.

Table 3: Average values and standard deviations for parameters measured in streams on ARGOS sheep/beef farms, averaged by cluster. N = 3 for all clusters except Cluster 4 (n = 2), and Cluster 12 (n = 2). For each farm, the values at the up- and down-stream sites were averaged. Parameter means with a – indicate clusters where no data was collected, and standard deviations with a – had only one value for the parameter in that cluster.

Cluster		Width (m)	Depth (m)	Temp (°C)	pH	Velocity (M/sec)	Clarity (m)	Stream bed	Bank vegetation	Invertebrate	Peri-phyton	YSI conductivity
1	Mean	-	-	-	-	-	-	-	-6.73	-	-	-
	Stand.Dev.	-	-	-	-	-	-	-	2.58	-	-	-
2	Mean	3.39	0.21	15.50	6.60	0.26	0.70	-6.87	-1.71	3.24	4.80	467.33
	Stand.Dev.	1.61	0.19	1.00	0.55	0.25	0.30	12.20	3.63	1.88	1.22	385.90
3	Mean	1.68	0.12	12.83	7.33	0.19	0.87	4.90	-1.91	6.45	2.53	197.00
	Stand.Dev.	0.52	0.05	2.39	0.52	0.14	0.10	4.43	0.43	0.84	1.34	118.10
4	Mean	2.95	0.10	17.30	7.00	0.14	-	-14.05	-7.66	2.83	1.32	90.00
	Stand.Dev.	1.66	0.08	-	-	0.13	-	8.03	3.05	1.23	1.53	60.23
5	Mean	1.58	0.15	19.25	7.00	0.43	0.19	-11.52	-6.86	2.31	3.19	68.33
	Stand.Dev.	0.74	0.06	2.33	-	0.26	0.10	11.53	2.05	0.51	3.68	3.06
6	Mean	1.52	0.13	-	7.00	0.36	0.08	-13.47	-7.85	2.02	1.62	59.00
	Stand.Dev.	0.74	0.05	-	-	0.24	0.05	8.79	0.28	0.73	2.62	10.64
7	Mean	1.82	0.10	-	6.83	0.31	-	-5.60	-8.17	3.72	3.75	44.83
	Stand.Dev.	0.80	0.04	-	0.29	0.31	-	11.55	2.07	0.80	1.86	31.44
8	Mean	1.62	0.13	8.83	7.00	0.24	0.62	-0.63	0.20	4.84	2.00	56.67
	Stand.Dev.	0.86	0.08	4.50	-	0.18	0.33	7.70	4.70	1.03	2.48	17.01
9	Mean	0.89	0.14	11.33	7.00	0.32	0.55	-2.53	-5.94	3.59	5.79	113.17
	Stand.Dev.	0.64	0.11	1.54	-	0.11	0.14	6.59	4.26	0.67	2.90	15.22
10	Mean	0.97	0.08	16.33	6.10	0.37	0.51	-5.77	-6.39	2.49	4.03	119.17
	Stand.Dev.	0.40	0.04	2.42	0.55	0.11	0.28	11.17	1.23	0.95	2.65	17.75
11	Mean	-	-	-	-	-	-	-	-9.98	-	-	-
	Stand.Dev.	-	-	-	-	-	-	-	0.04	-	-	-
12	Mean	1.50	0.05	-	-	-	-	-5.00	-5.85	-	-	-
	Stand.Dev.	-	-	-	-	-	-	-	2.84	-	-	-
	Grand mean	1.79	0.12	12.06	6.87	0.29	0.50	-6.05	-5.74	3.50	3.23	135.06
	Stand.Dev.	0.79	0.04	5.22	0.35	0.09	0.28	5.89	3.03	1.40	1.51	133.01
	%CV	44.14	35.80	43.30	5.05	31.69	55.44	-97.36	-52.80	40.04	46.73	98.48

Table 3 continued: Average values and standard deviations for parameters measured on ARGOS sheep/beef farms

Cluster		YSI salinity	YSI DO	YSI TDS	TOC (mg/L)	NH_4^+ (ug/L)	NO_2 + NO_3 (ug/L)	DRP (ug/L)	TP (ug/L)	Total sediment (g/L)	Organic Sediment (g/L)	Turbidity
1	Mean	-	-	-	-	-	-	-	-	-	-	-
	Stand.Dev.	-	-	-	-	-	-	-	-	-	-	-
2	Mean	0.22	0.43	0.36	-	-	-	-	-	3.33	0.67	-
	Stand.Dev.	0.13	0.34	0.33	-	-	-	-	-	5.33	0.67	-
3	Mean	0.13	0.86	0.15	-	-	-	-	-	-	-	-
	Stand.Dev.	0.08	0.13	0.09	-	-	-	-	-	-	-	-
4	Mean	0.05	1.00	0.06	7.15	20.19	2454.49	2.73	22.73	-	-	3.63
	Stand.Dev.	0.04	0.21	0.05	-	5.08	2847.65	4.46	13.57	-	-	0.83
5	Mean	0.04	1.05	0.05		-	-	-	-	13.34	0.67	-
	Stand.Dev.	0.01	0.04	-	-	-	-	-	-	18.00	1.33	-
6	Mean	0.03	0.91	0.04	-	-	-	-	-	8.00	0.67	-
	Stand.Dev.	0.01	0.19	0.01	-	-	-	-	-	7.33	0.67	-
7	Mean	0.02	0.83	0.04	8.33	27.18	234.99	42.72	77.65	-	-	2.63
	Stand.Dev.	0.02	0.14	0.02	0.67	9.38	348.96	64.89	66.42	-	-	1.22
8	Mean	0.04	0.83	0.05	9.88	22.12	56.23	4.26	61.03	2.67	0.00	2.65
	Stand.Dev.	0.01	0.02	0.02	4.47	35.79	80.15	2.54	25.41	2.67	0.67	1.75
9	Mean	0.09	0.90	0.12	9.85	20.49	309.82	9.30	68.09	6.67	0.67	7.25
	Stand.Dev.	0.02	0.05	0.02	-2.03	30.37	305.87	5.75	58.27	8.67	0.67	12.15
10	Mean	0.07	0.61	0.09	12.84	53.58	456.24	20.22	137.17	12.66	1.33	3.50
	Stand.Dev.	0.02	0.21	0.03	0.24	36.25	558.80	14.87	82.37	16.00	1.33	1.84
11	Mean	-	-	-	9.96	104.12	174.27	5.81	74.20	-	-	4.25
	Stand.Dev.	-	-	-	-	-	-	-	-	-	-	-
12	Mean	-	-	-	-	-	-	-	-	-	-	-
	Stand.Dev.	-	-	-	-	-	-	-	-	-	-	-
	Grand mean	0.08	0.82	0.11	9.71	44.91	610.41	14.12	73.04	8.00	0.67	3.99
	Stand.Dev.	0.06	0.19	0.10	1.92	31.73	914.30	15.37	37.16	4.67	0.67	1.72
	%CV	84.11	23.40	96.07	19.82	70.64	149.79	108.81	50.88	58.05	63.25	43.04

Table 4: Average values, standard deviations, percentage coefficients of variation and sample sizes for parameters measured in streams on ARGOS sheep/beef farms, averaged by panel. Significant differences were tested using a one-way analysis of variance with no blocking. Post-hoc pairwise differences were tested using Tukey's honestly significant difference. Values with different superscripts are significantly different at α = 0.05

Panel		**Width (m)**	**Depth (m)**	**Temp (℃)**	**pH**	**Velocity (m/sec)**	**Clarity (m)**	**Stream bed**	**Bank vegetation**	**Invertebrate**	**Periphyton**	**YSI conductivity**
Organic	Mean	2.11	0.13	14.54	6.90	0.74	0.62	-5.54	-5.91	3.80	2.58	106.22
	Stand.Dev.	1.39	0.05	3.23	0.28	1.41	0.38	9.66	3.23	1.41	2.18	80.88
	%CV	65.88	38.46	22.21	4.06	190.54	61.29	-174.37	-54.65	37.11	84.49612	76.143852
IM	Mean	1.66	0.12	14.22	6.94	2.92	0.44	-5.81	-6.06	3.33	3.23	98.61
	Stand.Dev.	0.63	0.07	3.83	0.44	7.99	0.30	7.63	2.94	1.81	2.32	51.65
	%CV	37.95	58.33	26.93	6.34	273.63	68.18	-131.33	-48.51	54.35	71.82663	52.378055
Conventional	Mean	1.53	0.14	13.65	6.77	0.41	0.54	-6.19	-4.93	3.43	3.96	214.1
	Stand.Dev.	1.02	0.13	3.08	0.68	0.25	0.18	10.27	5.13	1.72	0.61	295.9
	%CV	66.67	92.86	22.56	10.04	60.98	332.90	-165.91	-104.06	50.15	15.40404	138.20645
Significant difference		No	No	No	No	No	No	No	No	No	No	No

Cluster		YSI salinity	YSI DO	YSI TDS	TOC (mg/L)	NH_4^+ (ug/L)	NO_2 + NO_3 (ug/L)	DRP (ug/L)	TP (ug/L)	Total sediment (g/L)	Organic Sediment (g/L)	Turbidity
Organic	Mean	0.07	0.82	0.09	12.09a	27.33	1048.00	4.43	46.08	6.67	0.67	3.08a
	Stand.Dev.	0.05	0.17	0.07	2.81	5.97	2159.00	4.60	29.52	7.33	0.67	0.59
	%CV	71.43	20.73	77.78	23.24	21.84	206.01	103.84	64.06	110.00	100.00	19.16
IM	Mean	0.06	0.88	0.07	8.59b	35.49	243.40	34.45	92.51	6.67	0.67	2.94a
	Stand.Dev.	0.03	0.15	0.03	2.47	27.60	339.80	52.62	84.47	3.33	0.67	1.66
	%CV	50.00	17.05	42.86	28.72	77.76	139.60	152.77	91.31	50.00	100.00	56.46
Conventional	Mean	0.11	0.74	0.18	8.57b	49.74	388.8	6.79	82.38	8.66	0.67	7.75b
	Stand.Dev.	0.12	0.35	0.25	0.41	19.29	272.3	4.92	33.08	11.33	0.67	7.80
	%CV	109.09	47.30	138.89	4.76	38.79	70.0	75.52	40.15	130.77	100.00	100.65
Significant difference?		No	No	No	Yes	No	No	No	No	No	No	Yes

Table 5: Average values for parameters measured in streams on ARGOS dairy farms, averaged by cluster. N = 2 for all clusters. For each farm, the values at the up- and down-stream sites were averaged. Parameter means with a – indicate clusters where no data was collected, while standard deviations with a – had only one value for the parameter in that cluster.

Cluster		Width (m)	Depth (m)	Temp (℃)	pH	Velocity (M/sec)	Clarity (m)	Stream bed	Bank vegetation	Invertebrate	Periphyton	YSI conductivity
1	Mean	0.58	0.45	14.75	6.00	0.00	0.18	-19.50	-8.30	2.94	0.25	213.00
	Stand.Dev.	0.27	0.39	1.77	-	-	0.42	0.71	0.42	0.37	-	56.57
2	Mean	1.26	0.05	15.00	3.50	0.15	0.86	-16.00	-2.90	3.99	0.00	68.50
	Stand.Dev.	1.11	0.03	1.41	-	-	0.08	5.66	3.85	0.63	0.00	9.19
3	Mean	0.28	0.02	10.25	2.75	0.02	0.21	-9.95	-5.95	0.92	0.63	107.25
	Stand.Dev.	0.14	0.03	4.95	0.71	-	0.24	0.14	3.80	0.60	0.47	2.12
4	Mean	1.86	0.28	18.25	4.75	0.08	0.43	-18.50	-7.48	3.66	0.69	129.25
	Stand.Dev.	0.24	0.16	0.50	1.15	0.04	0.35	3.00	4.45	0.55	0.85	21.75
5	Mean	2.22	0.32	18.50	7.00	0.21	0.62	-14.00	-8.66	1.71	0.50	106.50
	Stand.Dev.	1.19	0.09	0.71	-	-	0.54	11.31	0.27	0.26	0.71	7.78
6	Mean	2.09	0.17	16.00	6.83	0.14	0.60	-6.00	-4.94	3.12	3.23	128.75
	Stand.Dev.	0.73	0.04	1.63	0.29	0.08	0.56	12.46	4.51	1.50	3.01	75.77
7	Mean	2.10	0.12	16.75	7.00	0.30	1.00	5.50	-1.84	5.58	6.55	203.50
	Stand.Dev.	0.76	0.02	1.19	-	0.19	0.01	1.82	4.94	1.20	1.94	83.24
8	Mean	1.00	0.03	18.25	7.00	0.16	0.66	-5.70	-8.84	2.64	4.51	498.00
	Stand.Dev.	0.63	0.01	1.06	-	0.10	0.90	13.15	1.54	0.75	4.97	82.02
9	Mean	2.92	0.22	15.13	7.50	0.19	0.45	-15.00	-4.34	2.82	1.20	350.25
	Stand.Dev.	1.56	0.14	2.17	1.29	-	0.44	10.00	4.80	1.80	1.88	160.52
10	Mean	-	-	-	-	-	-	-	-9.63	-	-	-
	Stand.Dev.	-	-	-	-	-	-	-	0.53	-	-	-
11	Mean	1.89	0.21	16.13	6.33	0.09	1.00	1.80	-6.96	4.30	2.06	121.50
	Stand.Dev.	0.88	0.13	1.03	0.58	-	0.00	9.42	1.06	0.87	1.10	13.92
12	Mean	-	-	-	-	-	-	-	-4.24	-	-	-
	Stand.Dev.	-	-	-	-	-	-	-	4.96	-	-	-
	Grand mean	1.62	0.19	15.90	5.87	0.13	0.29	-9.74	-6.17	3.17	1.96	192.65
	Stand.Dev.	0.82	0.14	2.43	1.64	0.09	0.56	8.52	2.53	1.32	2.16	134.12
	%CV	50.49	75.07	15.30	27.98	68.04	188.12	-87.48	-40.94	41.59	110.19	69.62

Table 5 continued: Average values and standard deviations of parameter measured on ARGOS dairy farms

Cluster		YSI salinity	YSI DO	YSI TDS	TOC (mg/L)	NH_4^+ (ug/L)	NO_2+NO_3 (ug/L)	DRP (ug/L)	TP (ug/L)	Total Sediment (g/L)	Organic Sediment (g/L)	Turbidity	E. coli	Coliforms
1	Mean	0.13	8.65	0.20	16.70	478.16	55.88	11.53	439.94	1.33	0.67	8.25	400.0	1050.0
	Stand.Dev.	0.04	8.27	0.00	0.42	-	-	-	24.71	-	-	0.35	-	-
2	Mean	0.04	0.53	0.05	3.87	48.14	473.78	4.50	33.20	4.67	0.67	2.00	53.0	75.5
	Stand.Dev.	0.01	0.09	0.01	1.14	13.88	231.83	2.99	17.57	4.67	0.67	0.71	-	-
3	Mean	0.05	0.20	0.07	2.68	31.37	2206.86	4.56	62.52	0.67	0.00	6.69	840.0	845.0
	Stand.Dev.	0.00	0.11	0.00	-	14.22	428.80	12.19	138.87	0.67	0.00	15.03	-	-
4	Mean	0.07	0.34	0.10	4.11	37.37	4.79	1.54	57.57	0.67	0.00	2.31	490.0	490.0
	Stand.Dev.	0.01	0.32	0.02	2.04	25.07	12.84	3.64	22.15	0.67	0.00	0.88	-	-
5	Mean	0.05	0.48	0.08	2.82	103.89	1762.01	7.80	13.09	0.67	0.67	1.00	40.5	80.5
	Stand.Dev.	0.02	0.19	0.00	0.23	96.86	27.51	7.37	4.02	0.00	0.00	-	-	-
6	Mean	0.07	0.75	0.10	4.08	57.80	275.54	0.88	11.11	12.67	1.33	2.19	222.5	252.5
	Stand.Dev.	0.05	0.03	0.06	0.78	6.54	146.60	0.75	4.83	19.33	0.67	1.48	173.2	194.5
7	Mean	0.11	0.82	0.16	6.31	36.38	492.59	17.68	137.60	12.00	2.00	2.94	162.5	192.5
	Stand.Dev.	0.05	0.04	0.07	2.26	19.19	516.63	7.79	150.35	10.00	1.33	2.25	88.4	109.6
8	Mean	0.28	0.52	0.37	20.42	81.84	7518.75	1648.06	3931.62	12.00	2.00	7.00	1950.0	2550
	Stand.Dev.	0.05	0.25	0.07	3.89	71.34	375.44	391.07	1464.02	11.33	1.33	0.71	-	-
9	Mean	0.21	0.35	0.28	17.74	1252.63	94.62	544.05	795.03	2.67	0.67	7.94	1090.0	1615.0
	Stand.Dev.	0.11	0.25	0.14	9.19	1532.46	110.57	690.27	1091.84	4.00	1.33	2.40	-	1464.0
10	Mean	-	-	-	-	-	-	-	-	-	-	-	-	-
	Stand.Dev.	-	-	-	-	-	-	-	-	-	-	-	-	-
11	Mean	0.07	0.37	0.09	6.95	25.43	0.50	10.03	59.15	4.00	0.67	2.38	710.0	920.0
	Stand.Dev.	0.01	0.05	0.01	1.35	4.56	0.00	7.63	31.34	4.00	0.67	1.44	226.3	304.1
12	Mean	-	-	-	-	-	-	-	-	-	-	-	-	-
	Stand.Dev.	-	-	-	-	-	-	-	-	-	-	-	-	-
	Grand mean	0.11	1.30	0.15	8.57	215.30	1288.53	225.06	554.08	5.33	0.67	4.27	584.5	789.4
	Stand.Dev.	0.08	2.59	0.10	6.90	388.97	2320.41	527.70	1213.09	5.33	0.67	2.83	580.9	843.2
	%CV	73.49	199.03	68.94	80.53	180.66	180.08	234.47	218.94	101.91	83.33	66.24	99.4	106.8

Table 6: Average values, standard deviations, percentage coefficients of variation and sample sizes for parameters measured in streams on ARGOS dairy farms, averaged by panel. Significant differences were tested using a one-way analysis of variance with no blocking.

Panel		Width (m)	Depth (m)	Temp (℃)	pH	Velocity (M/sec)	Clarity (m)	Stream bed	Bank vegetation	Invertebrate	Periphyton	YSI conductivity
Organic	Mean	1.83	0.13	16.32	6.83	0.21	0.16	-8.16	-5.75	3.57	2.75	179.71
	Stand.Dev.	0.69	0.09	1.80	0.94	0.14	0.33	10.32	4.11	0.87	3.39	146.88
	%CV	37.70	69.23	11.03	13.76	66.67	207.55	-126.47	-71.48	24.37	123.27	81.73
Conventional	Mean	1.62	0.22	15.25	4.36	0.08	0.24	-9.16	-5.81	3.01	1.63	189.89
	Stand.Dev.	1.26	0.19	2.45	0.78	0.10	0.64	12.80	4.02	1.86	1.88	122.19
	%CV	77.78	86.36	16.07	17.89	125.00	265.29	-139.74	-69.19	61.79	115.34	64.35
	Significant difference	No	No	No	No	No	No	No	No	No	No	No

Panel		YSI salinity	YSI DO	YSI TDS	TOC (mg/L)	NH_4^+ (ug/L)	NO_2 + NO_3 (ug/L)	DRP (ug/L)	TP (ug/L)	Total Sediment (g/L)	Organic Sediment (g/L)	Turbidity	E. coli	Coliforms
Organic	Mean	0.10	0.49	0.14	7.94	51.03	1295.62	241.65	621.84	7.33	1.33	3.89	539.0	661.5
	Stand.Dev.	0.08	0.25	0.11	5.81	31.41	2660.56	605.68	1462.52	6.67	1.33	2.42	660.2	870.4
	%CV	80.00	51.02	78.57	73.17	61.55	205.35	250.64	235.19	90.91	100.00	62.21	122.5	131.6
Conventional	Mean	0.11	1.38	0.15	7.55	359.64	765.65	126.42	256.76	2.67	0.67	4.43	630.1	917.2
	Stand.Dev.	0.08	3.51	0.10	8.06	960.03	1611.29	429.79	605.91	11.33	0.67	6.09	538.9	863.1
	%CV	72.73	254.35	66.67	106.75	266.94	210.45	339.97	235.98	425.00	100.00	137.47	85.5	94.1
	Significant difference	No	No	No	No	No	No	No	No	No	Yes	No	No	No

Table 7: Average values, standard deviations, percentage coefficients of variation and sample sizes for parameters measured in streams on ARGOS sheep/beef and dairy farms. Significant differences were tested using a one-way analysis of variance with no blocking.

Sector		width	depth	temp	pH	velocity	Clarity	Stream bed	Bank vegetation	Invertebrate	Periphyton
Dairy	Mean	1.62	0.19	15.90	5.87	0.13	2.98	-9.74	-6.17	3.17	1.96
	Stand.Dev.	0.82	0.14	2.43	1.64	0.09	5.61	8.52	2.53	1.32	2.16
	Sample size	15.00	15.00	15.00	15.00	11.00	14.00	15.00	19.00	15.00	15.00
	%CV	50.49	75.07	15.30	27.98	68.04	188.12	-87.48	-40.94	41.59	110.19
Sheep/beef	Mean	1.79	0.12	12.06	6.87	0.29	0.50	-6.05	-5.74	3.50	3.23
	Stand.Dev.	0.79	0.04	5.22	0.35	0.09	0.28	5.89	3.03	1.40	1.51
	Sample size	27.00	27.00	17.00	25.00	24.00	21.00	27.00	34.00	26.00	24.00
	%CV	44.14	35.80	43.30	5.05	31.69	55.44	-97.36	-52.80	40.04	46.73
	Significant difference	No	Yes	Yes	No	No	No	No	No	No	No

Sector		YSI salin-ity	YSI DO	YSI TDS	TOC (mg/L)	NH_4^+ (ug/L)	NO_2 + NO_3 (ug/L)	DRP (ug/L)	TP (ug/L)	Total Sedi-ment	Organi c Sedi-ment	Turbi-dity	E.coli	Coli-forms
Dairy	Mean	0.11	1.30	0.15	8.57	215.30	1288.53	225.06	554.08	0.08	0.01	4.27	584.5	789.4
	Stand. Dev.	0.08	2.59	0.10	6.90	388.97	2320.41	527.70	1213.09	0.08	0.01	2.83	580.9	843.2
	Sample size	15.00	15.00	15.00	15.00	14.00	14.00	14.00	15.00	15.00	15.00	15.00	99.4	109.9
	%CV	73.49	199.03	68.94	80.53	180.66	180.08	234.47	218.94	101.91	83.33	66.24		
Sheep/ beef	Mean	0.08	0.82	0.11	9.71	44.91	610.41	14.12	73.04	0.12	0.01	3.99		
	Stand. Dev.	0.06	0.19	0.10	1.92	31.73	914.30	15.37	37.16	0.07	0.01	1.72		
	Sample size	26.00	26.00	26.00	13.00	14.00	14.00	14.00	14.00	17.00	17.00	14.00		
	%CV	23.40	96.07	19.82	70.64	149.79	108.81	50.88	58.05	63.25	43.04	43.04		
	Significant difference	No	No	No	No	No (P = 0.07)	No	No (P = 0.08)	No (P = 0.09)	No	No	No		

Percentage change across sheep/beef farms

The average percentage change in measured water clarity and quality indicators across ARGOS sheep/beef farms (between upstream and downstream sites) in each cluster is shown in Table 8. The direction and degree of change was highly variable between clusters, although levels of nutrients and sediments tended to increase across farms rather than decrease. Clusters that had percentage increases in total and organic sediment also had increased turbidity readings and increased clarity tube readings, while clusters where there was a percentage decrease in sediment loads also had decreased turbidity and clarity tube readings.

The average relative change in water quality and stream health indicators by panel is shown in Table 9. There were no consistent or significant differences in the direction or magnitude of percentage change between sheep/beef panels. Relative levels of NH_4^+ decreased on both IM and Conventional farms but increased on Organic farms, while relative levels of DRP decreased on Organic farms, but increased on both IM and Conventional farms. Relative levels of NO_2 + NO_3, TP, and organic and total sediment increased on all panels. The relative invertebrate community scores decreased on IM farms but increased on Organic and Conventional farms, while the periphyton score increased on Conventional farms but decreased in the other two panels.

Percentage change across dairy farms

The average percentage change in measured water clarity and quality indicators across ARGOS dairy farms in each cluster is shown in Table 10. Directions and relative levels of change were highly variable between clusters; in most cases approximately half the clusters showed relative increases or decreases in the measured parameters. Some parameters, such as organic and total sediment and concentrations of *E. coli* and fecal coliforms were highly variable between clusters, with values ranging from -80% to +10,330 % for total sediment, and from -87 % to + 15,900 % for *E. coli.* There were too many missing values to allow statistical testing of differences between clusters.

The average relative change in water quality and stream health indicators by Panel is shown in Table 11. There were no consistent directions or significant differences between the panels, although the differences did approach formal statistical significance for NH_4^+, organic and total sediment, and turbidity (Table11). There were larger relative increases in NH_4^+, NO_2 + NO_3, DRP and total phosphorous on Organic Conversion that Conventional farms, while the relative increases in organic and total sediment were greater on Conventional dairy farms. Relative invertebrate and periphyton scores decreased on Organic Conversion farms, while both indices increased on Conventional farms. In comparison, relative increases in *E. coli* and fecal coliforms were much larger on Conventional farms than on Organic Conversion farms, although the data was highly variable (%CV's of more than 200 %) and the differences were not significant.

Sector comparisons of percentage changes

The relative changes in water quality indicators in each sector are shown in Table 12. Relative increases in NH_4^+, DRP, TP, Total and organic sediment and turbidity were all greater on ARGOS dairy farms than on sheep/beef farms, although none of these differences were significant (relative change in total sediment approached statistical significance). Relative increases in NO_2 + NO_3 were larger on sheep/beef than on dairy properties (statistical test approached significance; P = 0.07), while there were small and similar changes in the invertebrate score (small increase), periphyton score (small decrease) and TOC (small increase) in both sectors.

3.2 Water quality and clarity

Water quality and clarity in sheep/beef farms

A principle components analysis of the percentage change in water clarity indicators was performed for all sites with water present at the time of survey. The variables included were: the percentage change in clarity tube reading, the percentage change in organic sediment and the percentage change in total sediment. Percentage change was used to isolate the effect on on-farm influences on water quality and to control for differing upstream influences, and was calculated as ((Downstream value – Upstream value)/Upstream value) x 100).

At an individual site, a positive value for percent change in sediment measures indicated increasing water clarity (more suspended sediment has settled out), while a positive percent change for the clarity reading also indicates cleaner water. The results of the PCA are shown in Figure 3. Sites positively associated with Axis 1 had greater changes in clarity and sediment levels across the farm, indicating increased water clarity. Sites positively associated with Axis 2 had greater increases in clarity tube readings, and smaller increases in organic sediment loading (Table 13). PCA Axis 1 explains 48.4 % of the variation and Axis 2 explains 35.4 % variation. A One-way ANOVA showed no significant difference between panels in PCA scores, either for PCA Axis 1 ($F_{2,11}$ = 2.71, P = 0.110. Averages ± standard error: Organic = -0.23 ± 0.21, IM = -0.10 ± 0.09, Conventional = -0.39 ± 0.26), or PCA Axis 2 ($F_{2,11}$ = 0.02, P = 0.976. Organic = -0.23 ± 0.41, IM = -0.24 ± 0.29, Conventional = 0.33 ± 0.95).

Water quality and clarity in dairy farms

As for the sheep/beef farms, a principle components analysis of the percentage change in water clarity indicators was performed for all sites with water present at the time of survey. The variables included were the percent change in clarity tube reading, the percent change in organic sediment and the percentage change in total sediment. The results of the PCA are shown in Figure 4. PCA Axis 1 explains 48.5% of the variation and Axis 2 explains 37.7% variation. The axis loadings are shown in Table 14.

Sites positively associated with Axis 1 have greater sediment increases across the farm, while sites positively associated with Axis 2 have the greatest increase in clarity (i.e. lower sediment inputs or better filtering of inputs as the stream flows across the farm). There were no significant differences in the amount of change in water clarity across the farm between panels, for either PCA Axis 1 ($F_{1,10}$ = 0.00, P = 0.949. Averages ± standard error: Organic Conversion= 0.01 ± 0.47, Conventional = -0.04 ± 1.05) or Axis 2 ($F_{1,10}$ = 0.02, P = 0.881. Organic Conversion = 0.02 ± 0.45, Conventional = -0.07 ± 0.49).

Table 8: Average percentage change (and standard deviations) in measured parameters across individual AGROS sheep/beef farms, averaged by cluster. Parameter means with a – indicate clusters where no data was collected, while standard deviations with a – indicate that the percentage change could only be calculated for one farm in the cluster.

Cluster	Parameter	Invertebrate	Periphyton	TOC (mg/L)	NH_4^+ (ug/L)	NO2 + NO3 (ug/L)	DRP (ug/L)	TP (ug/L)	Total Sediment	Organic Sediment	Turbidity	Clarity tube
1	Mean	-	-	-	-	-	-	-	-	-	-	-
	Stand.Dev.	-	-	-	-	-	-	-	-	-	-	-
2	Mean	-22.45	-30.40	-	-	-	-	-	116.22	451.52	-	29.39
	Stand.Dev.	37.21	9.30	-	-	-	-	-	194.23	562.27	-	104.95
3	Mean	-17.90	0.68	-	-	-	-	-	-	-	-	19.58
	Stand.Dev.	21.58	64.98	-	-	-	-	-	-	-	-	47.28
4	Mean	-71.94	-100.00	-24.72	6.19	7.58	891.75	90.91	-	-	0.48	-
	Stand.Dev.	10.47	-	-	13.16	10.72	1261.12	70.82	-	-	37.89	-
5	Mean	1.55	-88.85	-	-	-	-	-	57.88	157.41	-	-1.66
	Stand.Dev.	20.23	15.78	-	-	-	-	-	236.22	268.53	-	44.60
6	Mean	-4.38	342.86	-	-	-	-	-	3.07	1984.03	-	140.90
	Stand.Dev.	21.97	-	-	-	-	-	-	131.91	3478.20	-	272.84
7	Mean	10.87	-65.24	-2.16	63.47	2066.52	50.02	28.11	-	-	-0.32	-
	Stand.Dev.	66.06	31.30	56.80	91.67	3668.86	101.00	50.03	-	-	29.28	-
8	Mean	45.47	-91.18	25.00	194.6	-18.6	-44.33	53.20	436.66	233.33	66.07	18.22
	Stand.Dev.	164.85	12.48	41.52	361.9	72.70	40.55	118.50	315.57	404.15	154.05	45.70
9	Mean	35.13	-9.66	0.91	-46.55	235.79	-48.95	-44.41	-71.93	-55.28	-53.99	19.41
	Stand.Dev.	29.61	2.96	39.79	41.65	428.21	45.86	31.19	40.73	48.94	35.78	46.94
10	Mean	81.66	-40.38	-10.34	22.43	652.95	49.75	9.75	-85.02	-79.37	-24.31	-46.27
	Stand.Dev.	114.16	32.15	36.04	7.62	89.92	33.30	33.20	16.15	25.82	18.66	-
11	Mean	-	-	-	-	-	-	-	-	-	-	-
	Stand.Dev.	-	-	-	-	-	-	-	-	-	-	-
12	Mean	-	-	-	-	-	-	-	-	-	-	-
	Stand.Dev.	-	-	-	-	-	-	-	-	-	-	-
	Grand mean	6.45	-9.13	-0.78	0.60	582.69	175.13	31.51	76.15	448.61	-2.41	25.65
	Standard deviation	44.35	136.89	21.05	46.21	874.25	404.26	53.65	192.43	777.34	44.28	56.78
	%CV	688.09	-1499.63	-2704.83	7673.56	150.04	230.83	170.28	252.72	173.28	-1834.84	221.36

Table 9: Average percentage change (and standard deviations) in measured parameters across individual AGROS sheep/beef farms, averaged by panel. Significant differences were tested using a one-way analysis of variance with no blocking. Post-hoc pairwise differences were tested using Tukey's honestly significant difference. Values with different superscripts are significantly different at α = 0.05

Panel		**Invertebrate**	**Periphyton**	**TOC (mg/L)**	**NH_4^+ (ug/L)**	**NO_2 + NO_3 (ug/L)**	**DRP (ug/L)**	**TP (ug/L)**	**Total Sediment**	**Organic Sediment**	**Turbidity**	**Clarity tube**
Organic	Mean	23.96	-51.31	25.47	10.04[a]	1352.84	-3.77	50.80	101.24	8.07	28.71	0.47
	Stand. Dev.	83.57	34.18	37.85	82.83	2780.83	54.73	78.67	356.06	83.40	84.69	36.15
	%CV	348.83	-66.61	148.61	824.99	205.56	-1453.19	154.86	351.69	1033.84	294.98	7645.60
IM	Mean	-22.34	-50.04	-12.60	4.53[a]	270.29	326.9	5.80	38.48	108.17	-32.00	70.60
	Stand. Dev.	39.13	53.10	33.87	24.15	414.72	815.53	78.12	168.87	302.63	9.03	191.00
	%CV	-175.14	-106.11	-268.77	533.38	153.44	249.48	1346.75	438.89	279.78	-28.22	270.56
Conventional	Mean	28.93	27.29	-4.03	206.30[b]	18.84	45.90	9.70	123.46	1491.38	-30.99	34.06
	Stand. Dev.	88.78	183.60	48.70	358.90	26.36	105.80	77.90	196.28	2564.18	90.97	75.37
	%CV	306.92	672.84	-1122.50	174.00	139.90	230.70	802.8	158.98	171.93	-293.54	221.31
Significant difference		No	No	No	Yes	No	No	No	No	No	No	No

Table 10: Average percentage change (and standard deviations) in measured parameters across individual ARGOS dairy farms, averaged by cluster. Parameter means with a – indicate clusters where no data was collected, while standard deviations with a – indicate that the percentage change could only be calculated for one farm in the cluster.

Cluster		Invertebrate	Periphyton	TOC (mg/L)	NH_4^+ (ug/L)	NO2 + NO3 (ug/L)	DRP (ug/L)	TP (ug/L)	Total Sediment	Organic Sediment	Turbidity	Clarity tube	E. coli	Coliforms
1	Mean	19.3	-	3.6	-	-	-	-7.6	-	-	-5.9	-28.6	-85.7	-60.0
	Stand.Dev.	-	-	0.0	-	-	-	-	-	-	-	-	-	-
2	Mean	-20.0	-	53.0	51.2	105.8	-64.0	-54.5	-80.0	-86.4	-40.0	-11.7	-10.7	47.5
	Stand.Dev.	-	-	0.0	-	-	-	-	-	-	-	-	-	-
3	Mean	59.3	-41.7		38.2	-12.9	-97.2	-88.0	-68.8	2000.0	-88.5	133.3	-88.0	-87.3
	Stand.Dev.	-	-		-	-	-	-	-	-	-	-	-	-
4	Mean	-11.5	75.0	-28.8	62.2	-97.3	-91.1	-38.2	400.0	33.3	77.8	148.5	-91.1	-91.1
	Stand.Dev.	11.6	-	0.0	-	-	-	-	-	-	-	261.4	-	-
5	Mean	-19.6	-	-10.8	-79.5	-2.2	-80.2	-35.7	-33.3	20.0	0.0	-76.0	15900.0	15900.0
	Stand.Dev.	-	-	0.0	-	-	-	-	-	-	-	-	-	-
6	Mean	90.7	-72.9	7.2	-5.2	16.2	150.2	88.0	10330.1	636.7	40.2	-79.3	38.7	61.8
	Stand.Dev.	74.4	-	18.1	1.5	66.8	212.4	53.6	14146.7	278.1	131.7	-	66.5	94.4
7	Mean	-8.2	3.1	-9.5	-62.6	-30.0	-30.5	130.0	-19.9	4026.4	70.1	-0.8	50.0	60.7
	Stand.Dev.	3.9	49.2	22.7	0.7	22.9	8.9	176.4	-	5619.5	152.2	1.2	50.5	96.0
8	Mean	-33.6	-87.5	-23.7	321.3	-6.8	-28.7	-41.7	-78.2	-79.1	-13.3	-55.7	16.7	21.7
	Stand.Dev.	-	-	0.0	-	-	-	-	-	-	-	-	-	-
9	Mean	-4.6	-95.0	15.5	13.2	-11.7	1309.7	231.0	543.8	560.0	-27.7	-11.3	-85.9	-75.7
	Stand.Dev.	12.1	7.1	28.6	81.5	16.5	1704.7	42.5	-	-	25.1	9.4	11.5	26.7
10	Mean	-	-	-	-	-	-	-	-	-	-	-	-	-
	Stand.Dev.	-	-	-	-	-	-	-	-	-	-	-	-	-
11	Mean	23.7	160.9	28.9	20.5	0.0	94.9	202.3	653.6	85.2	-27.8	0.0	404.4	495.0
	Stand.Dev.	4.8	6.8	14.6	4.1	-	35.8	181.0	287.9	85.2	39.3	-	700.9	829.9
12	Mean	-	-	-	-	-	-	-	-	-	-	-	-	-
	Stand.Dev.	-	-	-	-	-	-	-	-	-	-	-	-	-
	Grand mean	9.5	-8.3	3.9	39.9	-4.3	129.2	38.6	1294.1	799.6	-1.5	2.0	1604.8	1627.3
	Stand.Dev.	39.3	95.5	26.0	116.0	52.5	450.9	115.1	3401.1	1378.4	51.4	83.7	5025.0	5017.9
	%CV	411.7	-1152.1	665.6	290.8	-1216.7	348.9	298.5	262.8	172.4	-3391.1	4096.2	313.1	308.4

Table 11: Percentage change (and standard deviations) in measured parameters across individual AGROS dairy farms, averaged by panel. Significant differences were tested using a one-way analysis of variance with no blocking.

Panel		Invertebrate	Periphyton	TOC (mg/L)	NH_4^+ (ug/L)	NO_2 + NO_3 (ug/L)	DRP (ug/L)	TP (ug/L)	Total Sediment	Organic Sediment	Turbidity	Clarity tube	E. coli	Coliforms
Organic	Mean	-5.6	-13.3	3.4	65.1	-10.8	339.5	108.8	220.4	152.3	33.5	25.8	127.5	174.7
	Stand.Dev.	25.4	109.4	32.7	122.1	61.9	960.7	167.3	270.2	252.8	95.3	139.1	348.4	410.3
	%CV	-453.7	-823.9	974.3	187.4	-574.0	283.0	153.7	122.6	166.0	284.5	539.9	273.4	234.9
Conventional	Mean	28.1	15.5	8.9	-21.8	1.9	51.8	39.3	5272.1	2175.7	-27.8	-3.7	2223.3	2227.4
	Stand.Dev.	52.5	103.4	18.2	47.6	31.3	152.8	100.1	10050.0	3355.1	33.6	65.7	6031.0	6029.1
	%CV	186.9	668.0	203.4	-218.4	1669.3	295.0	254.5	190.6	154.2	-120.6	-1799.3	271.3	270.7
Significant difference		No	No	No	No (P = 0.07)	No	No	No	No (P = 0.09)	No (P = 0.07)	No (P = 0.09)	No	No	No

Table 12: Percentage change (and standard deviations) in measured parameters across individual AGROS dairy and sheep/beef farms. Significant differences were tested using a one-way analysis of variance with no blocking.

Sector	Parameter	Invertebrate	Periphyton	TOC (mg/L)	NH_4^+ (ug/L)	NO_2 + NO_3 (ug/L)	DRP (ug/L)	TP (ug/L)	Total Sediment	Organic Sediment	Turbidity
Dairy	Mean	9.50	-8.3	3.91	39.91	-4.31	129.23	38.57	1294.13	799.58	-1.51
	Stand.Dev.	39.3	95.5	26.00	116.04	52.45	450.91	115.13	3401.09	1378.38	51.37
	Sample size	15	10	13	13	13	13	14	11	12	14
	%CV	411.7	-1152.1	665.56	290.75	-1216.69	348.92	298.52	262.81	172.39	-3391.13
Sheep/beef	Mean	6.45	-9.13	-0.78	0.60	582.69	175.13	31.51	76.15	448.61	-2.41
	Stand.Dev.	44.35	136.89	21.05	46.21	874.25	404.26	53.65	192.43	777.34	44.28
	Sample size	26	19	12	13	12	13	12	17	17	12
	%CV	688.09	-1499.63	-2704.83	7673.56	150.04	230.83	170.28	252.72	173.28	-1834.84
	Significant difference	No	No	No	No	No (P = 0.07)	No	No	No (P = 0.08)	No	No

Table 13: PCA Axis 1 and 2 loadings (eigenvectors) for each variable used in the water clarity analysis on ARGOS sheep/beef properties. Axis 1 is most strongly correlated with relative increases in clarity tube readings, organic and total sediment, while Axis 2 is positively correlated with increases in clarity tube readings, and negatively with increases in sediment load.

Variable	PCA Axis 1	PCA Axis 2
Percent clarity tube change	0.618	0.502
Percent total sediment change	0.300	-0.862
Percent organic sediment change	0.727	-0.072

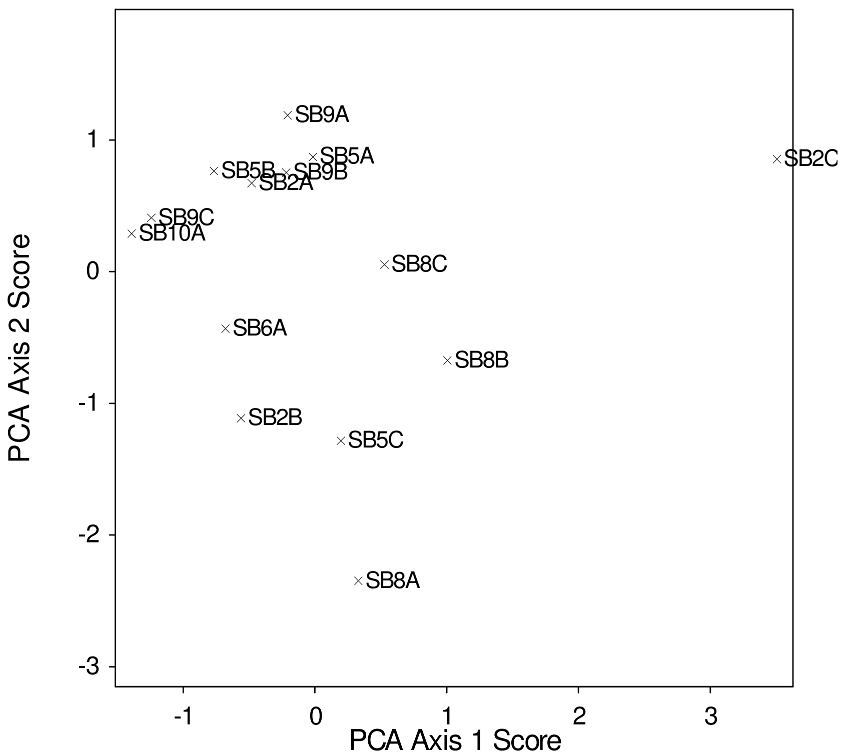

Figure 3: Sheep/beef water clarity PCA (correlation matrix) using % change from upstream to downstream SHMAK site. All sites with data were included except 6B (stream types completely different at sampling sites, making sediment comparisons invalid).

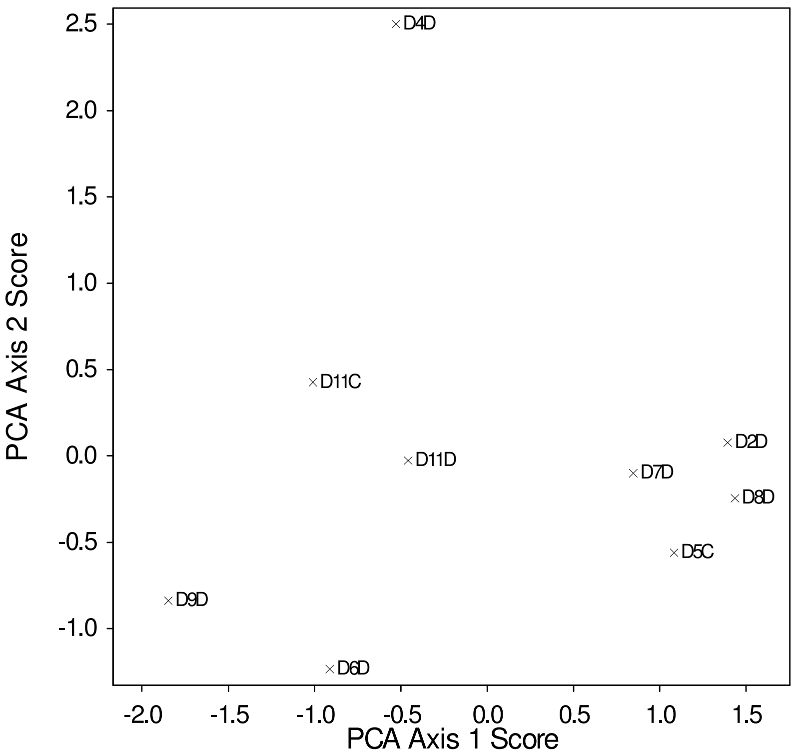

Figure 4: Dairy water clarity PCA (correlation matrix) using % change from upstream to downstream SHMAK site. All sites with data included except 3C (2000% increase in organic sediment from lab results, yet 68% decrease in total sediment and 133% increase in clarity).

Table 14: PCA Axis 1 and 2 loadings (eigenvectors) for each variable used in the water clarity analysis on ARGOS dairy properties. Axis 1 is most strongly correlated with relative increases in organic and total sediment, while Axis 2 is positively correlated strongly with increases in clarity tube readings and weakly with percent change in total sediment, and negatively correlated with increases in organic sediment load.

Variable	PCA Axis 1	PCA Axis 2
Percent clarity change	0.190	0.874
Percent total sediment change	0.736	0.174
Percent organic sediment change	0.650	-0.452

Nutrient loadings in sheep/beef farms

A principle components analysis of the percentage change in nutrient concentrations was performed for all sites with water present at the time of survey. The variables included were the percent dissolved reactive phosphorous (DRP), ammonia (NH_4^+), nitrate and nitrite (NO_2 + NO_3), total organic carbon (TOC), and total phosphorous (TP). As with the water clarity analysis, percentage change was used to isolate the effect on on-farm influences on water quality and to control for differing upstream influences, and was calculated as ((Downstream value – Upstream value)/Upstream value) x 100). The results of the PCA are shown in Figure 5. PCA Axis 1 explained 40.3 % of the variation, and Axis 2 explained 25.1 % variation.

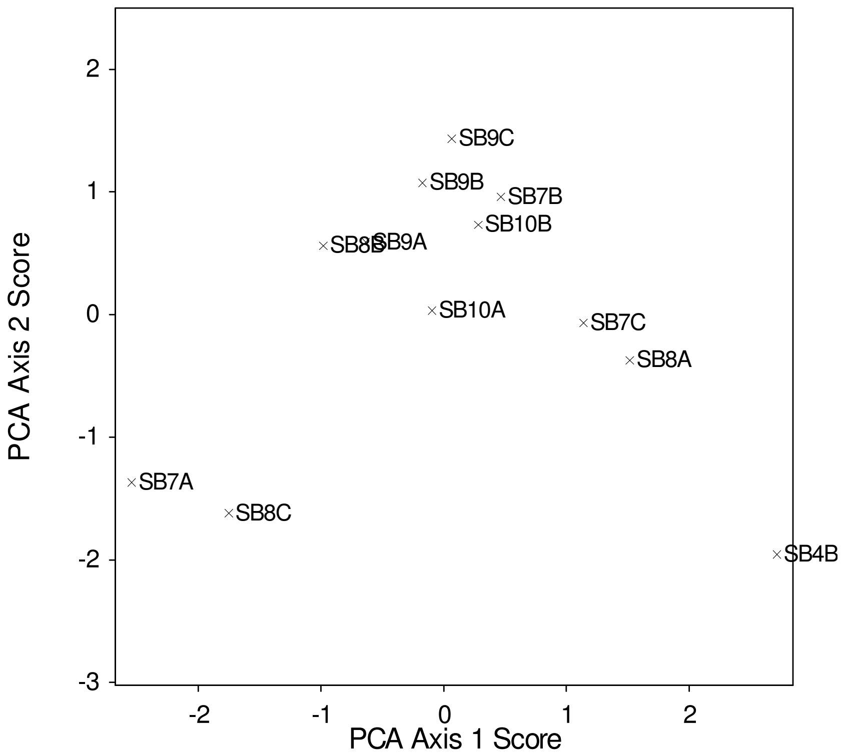

Figure 5: Sheep/beef nutrient PCA (correlation matrix). All sites with values included. Variables used were percent change in DRP, NH_4^+, NO_2 + NO_3, TOC, and TP. At a site, negative values indicate an increase in water quality for all variables. The PCA was highly influenced by farm 7A.

The relationships between individual variables and the PCA Axis scores are shown in Table 15. Sites to the right of Axis 1 have the smaller increases in nutrient loadings, as do sites lower down on Axis 2.

Table 15: PCA Axis scores for each surveyed stream. Sites negatively associated with Axis 1 had greater relative increases in nutrients across the farm (decreased water quality); while sites positively associated had smaller increases or reductions in nutrient loading (increased water quality). Sites negatively associated with Axis 2 had greater increases in nutrient loading.

Variable	PCA Axis 1	PCA Axis 2
DRP	0.451	-0.501
NH_4^+	-0.330	-0.533
NO_2 + NO_3	-0.407	-0.299
TOC	-0.569	-0.296
TP	0.447	-0.536

There were no significant differences in overall changes in nutrient loadings between panels, either for PCA Axis 1 ($F_{2,8}$ = 2.29, P = 0.164. Organic = -0.59 ± 1.16, IM = 0.19 ± 0.52, Conventional = 0.72 ± 0.06), or PCA Axis 2 ($F_{2,8}$ = 0.22, P = 0.808. Averages Organic = 0.14 ± 0.56, IM = -0.01 ± 0.66, Conventional = -0.25 ± 1.25).

Nutrient loadings in Dairy farms

A principle components analysis of the percentage change in nutrient concentrations was performed for all sites with water present at the time of survey. The variables included were the percentage DRP, NH_4^+, NO_2 + NO_3, TOC, and TP. The results of the PCA are shown in Figure 6. PCA Axis 1 explained 43.7% of the variation, while PCA Axis 2 explained 24.8% of the variation.

Sites positively associated with Axis 1 have decreases in nutrients (or smaller increases), specifically in N and TOC, as the stream flows through the farm. Sites negatively associated with Axes 2 have decreasing levels of N and increases in P as the stream flows though the farm (Figure 6, Table 16).

There were no significant differences in the amount of change in water quality across the farm between panels, for either PCA Axis 1 ($F_{1,10}$ = 0.05, P = 0.833 Averages Organic = 0.06, Conventional = -0.08) or Axis 2 ($F_{1,10}$ = 0.07, P = 0.790 Averages Organic = -0.07, Conventional = 0.09).

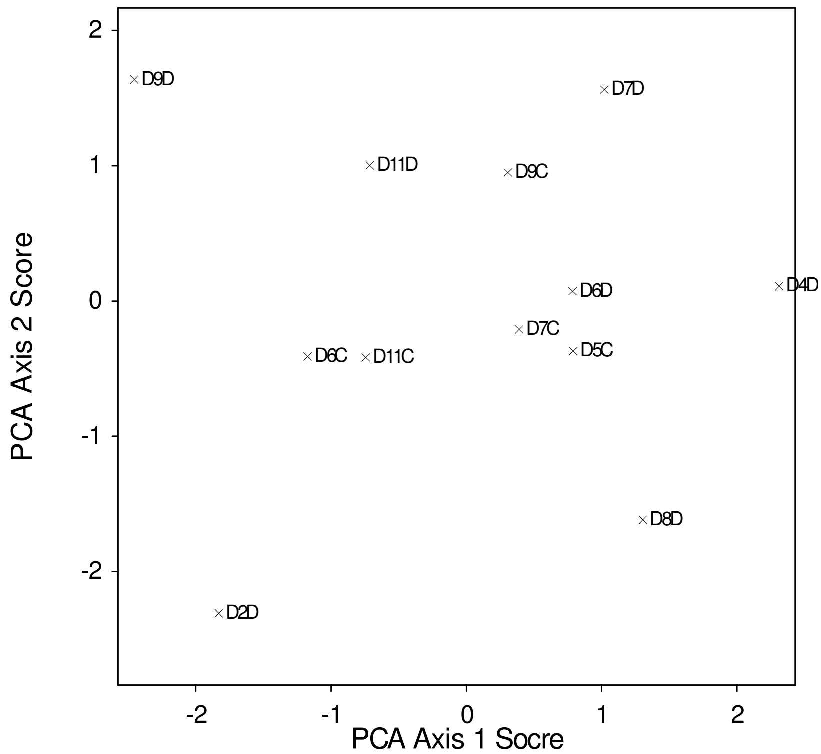

Figure 6: PCA of percentage change in nutrients on ARGOS dairy farms (correlation matrix). Variables used were percent change in DRP, NH_4^+, NO_2 + NO_3, TOC, and TP. At a site, negative values indicate an increase in water quality for all variables.

Table 16: Correlations between original variables and PCA Axis scores for nutrient change across AGROS dairy farms.

Variable	PCA Axis 1	PCA Axis 2
DRP	-0.441	-0.381
NH_4^+	0.046	0.347
$NO_2 + NO_3$	-0.541	0.460
TOC	-0.662	-0.182
TP	-0.268	-0.690

Relationships between water quality and stream health indicators in sheep/beef farms

The correlations between individual water clarity and quality variables, and multivariate measures of stream health, including the SHMAK score are shown in Table 17.
The overall increase in stream health as indicated by the SHMAK score was positively associated with increases in the clarity PCA Axis 1 score, percentage increases in DRP concentration and SHMAK invertebrate community score, and was negatively associated with percentage increases in organic and total sediment, and decreases in clarity tube readings. The correlations also identified the individual variables most important in the multivariate indicators derived from the PCA analyses. Percentage changes in total phosphorous, turbidity and total sediment are positively correlated with Clarity PCA Axis 1, while changes in NH_3, TOC and total sediment are positively correlated with Clarity PCA Axis 2. Nutrient PCA Axis 1 is positively correlated with increases in NH_4^+, $NO_2 + NO_3$, while PCA Axis 2 is positively correlated with changes in total phosphorous, TOC and turbidity.

Relationships between water quality and stream health indicators in dairy farms

The correlations between individual water clarity and quality variables, and multivariate measures of stream health, including the SHMAK score on ARGOS dairy farms are shown in Table 18.

The overall increase in stream health as indicated by the SHMAK score was positively associated with increases in the SHMAK invertebrate score, although this was not significant when P values were Bonferroni corrected. The correlations also identified the individual variables most important in the multivariate indicators derived from the PCA analyses. Percentage increases in organic and total sediment were significantly positively correlated with Clarity PCA Axis 1. Nutrient PCA Axis 1 was significantly negatively correlated with percent increases in $NO_2 + NO_3$, and TOC while Nutrient PCA Axis 2 was significantly negatively correlated with percent increases in TP. No other correlations were significant.

Table 17: Correlations between variables used in the analysis measured on ARGOS sheep/beef farms. Values in bold are significant following Bonferroni correction to control for family side type 1 errors (0.05/112.5) = 0.0004. The clarity PCA excludes sites 6B and 6C and the nutrient PCA excludes farm 7A. % SHMAK refers to the percent change in the overall SHMAK assessment score, and % Invert refers to the percent change in the SHMAK invertebrate score

	clarity PCA Axis1	**clarity PCA Axis2**	**nutrient PCA Axis 1**	**nutrient PCA Axis 2**	**% DRP**	**% NH_4^+**	**% NO_2 + NO_3**	**% SHMAK**	**% TOC**	**% Total P**	**% turbidity**	**% Invert**	**% organic sediment**	**% total sediment**	**% clarity tube**
clarity PCA Axis1	1.00														
clarity PCA Axis2	-0.49	1.00													
nutrient PCA Axis 1	0.34	-0.51	1.00												
nutrient PCA Axis 2	0.11	0.52	0.36	1.00											
% DRP	-0.76	-0.13	-0.15	-0.52	1.00										
% NH_4^+	0.20	-0.11	-0.65	-0.48	0.11	1.00									
% NO_2 + NO_3	-0.42	0.43	-0.97	-0.51	0.28	0.63	1.00								
% SHMAK	-0.95	0.51	-0.31	0.05	0.73	-0.13	0.33	1.00							
% TOC	0.34	0.27	0.19	0.65	-0.36	0.17	-0.27	-0.17	1.00						
% Total P	0.20	-0.79	0.47	-0.59	0.32	-0.04	-0.28	-0.36	-0.23	1.00					
% turbidity	0.35	-0.82	0.41	-0.63	0.16	0.01	-0.24	-0.53	-0.29	0.97	1.00				
% Invert	-0.76	0.50	-0.49	-0.19	0.65	0.22	0.60	0.69	0.10	-0.04	-0.19	1.00			
% organic sediment	0.77	-0.30	0.11	0.24	-0.53	0.48	-0.26	-0.55	0.51	-0.19	-0.10	-0.58	1.00		
% total sediment	0.60	-0.96	0.55	-0.47	-0.06	0.00	-0.46	-0.68	-0.26	0.83	0.90	-0.57	0.24	1.00	
% clarity tube	0.39	0.33	0.04	0.33	-0.76	-0.29	-0.06	-0.54	0.20	-0.09	0.04	-0.20	-0.09	-0.05	1.00

Table 18: Correlations between variables used in the analysis measured on ARGOS dairy farms. Values in bold are significant following Bonferroni correction to control for family side type 1 errors (0.05/112.5) = 0.0004. The clarity PCA excludes site 3C. % SHMAK refers to the percent change in the overall SHMAK assessment score, and % Invert refers to the percent change in the SHMAK invertebrate score

	Clarity PCA Axis 1	Clarity PCA Axis 2	Nutrient PCA Axis 1	Nutrient PCA Axis 2	% DRP	% NH_4^+	% NO_2 + NO_3	% SHMAK	% TOC	% TP	% turbidity	% Invert	% organic sediment	% total sediment	% clarity tube
Clarity PCA Axis 1	1.00														
Clarity PCA Axis 2	0.00	1.00													
Nutrient PCA Axis 1	-0.31	0.42	1.00												
Nutrient PCA Axis 2	-0.60	0.10	0.04	1.00											
% DRP	0.61	-0.31	-0.63	-0.49	1.00										
% NH_4^+	-0.18	0.09	0.08	0.45	0.08	1.00									
% NO_2 + NO_3	-0.34	-0.41	-0.73	0.56	0.07	0.08	1.00								
% SHMAK	0.25	-0.35	0.00	0.18	-0.04	0.36	-0.01	1.00							
% TOC	0.29	-0.23	-0.93	0.18	0.39	-0.09	0.77	0.09	1.00						
% TP	0.47	-0.27	-0.39	-0.83	0.46	-0.29	-0.12	-0.09	0.17	1.00					
% turbidity	-0.03	0.07	0.63	-0.32	-0.33	-0.36	-0.61	0.01	-0.63	0.01	1.00				
% Invert	0.59	-0.26	-0.16	-0.29	-0.08	-0.41	-0.08	0.51	0.28	0.36	0.18	1.00			
%organic sediment	0.78	-0.48	-0.35	-0.63	0.74	-0.19	-0.19	0.13	0.17	0.50	0.08	0.43	1.00		
% total sediment	0.89	0.19	-0.29	-0.40	0.37	-0.13	-0.25	0.40	0.39	0.36	-0.16	0.64	0.44	1.00	
% clarity tube	0.23	0.93	0.38	-0.13	-0.07	0.03	-0.55	-0.44	-0.27	-0.14	0.16	-0.22	-0.16	0.26	1.00

3.3 Comparison and calibration of SHMAK scores

Invertebrates in sheep/beef farms

SHMAK scores

The average SHMAK scores for organic, IM and conventional sheep/beef farms are shown in Table 19. On average, both organic and conventional sheep/beef farms had increases in SHMAK invertebrate scores, while IM farms had decreases in invertebrate scores. However, there was no significant difference in the percentage change in invertebrate score between the three panels, either when all farms with water were included ($F_{2,23}$ = 1.66, P = 0.213), or when farms with water were blocked by cluster ($F_{2,14}$ = 1.15, P = 0.346).

The average values for different univariate macro-invertebrate community indices in each panel are shown in Table 20. There were significantly more total individuals in streams on IM farms than on Conventional farms, although the differences between Organic and IM, or between Organic and Conventional were not significant. There were no other significant differences between the panels in the univariate community indices, and there were no significant differences in the univariate metrics between the six site groups (up and down stream sites in each panel).

The correlations between univariate macro-invertebrate community indices and the SHMAK invertebrate, riparian vegetation and stream bed score are shown in Table 21. There were significant positive correlations between the average SHMAK invertebrate score for a farm and both the average SHMAK bank vegetation score and stream bed scores. There were also significant positive correlations between the average percent EPT for a farm and the average percent insects and the three SHMAK scores. There were significant positive correlations between the average percent insects for a farm and the three SHMAK scores, and between the average SHMAK invertebrate score and the average species richness at a site.

Table 19: Average values for overall SHMAK scores and individual components on ARGOS sheep/beef farms. All farms with running water were included in the analyses with no blocking, while only farms from Clusters 2, 3, 5, 6, 7, 8, 9, and 10 were used in the blocked analysis.

Variable	Organic mean	n	Organic SE	IM mean	n	IM SE	Conventional mean	n	Conventional SE
Percent invertebrate change No blocking	23.96	9	27.86	-22.34	9	13.04	28.93	8	31.39
Percent invertebrate change blocking	36.87	8	27.99	-17.07	8	13.52	28.93	8	31.39
Percent periphyton change No blocking	-51.31	6	13.95	-50.04	8	18.77	27.29	5	82.11
Percent periphyton change blocking	-41.57	5	12.24	-42.90	7	20.05	27.29	5	82.11
Percent SHMAk change No blocking	9.14	9	30.17	-12.96	9	7.75	87.29	8	52.65
Percent SHMAk change blocking	19.65	8	32.07	-14.58	8	8.59	87.29	8	52.65
Bank vegetation average No blocking	-5.859	12	0.740	-6.816	11	0.911	-5.757	11	1.25
Bank vegetation average blocking	-5.57	8	0.998	-5.879	8	1.079	-4.580	8	1.52

Table 20: Univariate macro-invertebrate community indices from ARGOS sheep/beef farms. Percent insects indicates what proportion of the total invertebrates recorded were insects, and percent EPT refers to the proportion of total invertebrates that were Ephemeroptera (mayflies), Plecoptera (stoneflies) and Trichoptera (caddisflies). For an explanation of the SHMAK invert score, see Table 1. Sites with the same superscript are not significantly different using Tukeys Honestly Significant Difference post hoc test at α = 0.05

Panel		Total individuals	Taxa richness	Percent insects	Percent EPT	SHMAK invert score
Organic	Mean	178.6[ab]	6.9	26.8	27.5	3.8
	Standard deviation	103	2.1	24	17.6	1.41
	%CV	57.7	31.1	89.5	64	37.11
IM	Mean	243.4[b]	6	20.5	22.2	3.33
	Standard deviation	145.5	1.9	29.2	21.5	1.81
	%CV	59.8	30.8	142.3	97.1	54.35
Conventional	Mean	135.3[a]	5.8	28.1	29.33	3.43
	Standard deviation	98	2.3	32.9	28	1.72
	%CV	72.4	40.4	116.9	95.5	50.15
	Difference	Yes	No	No	No	No

Table 21: Pearsons Correlation coefficents for the relationships between average values for each univariate macro-invertebrate community index on each ARGOS sheep/beef farm and the average values for the SHMAK invertebrate, bank vegetation, and stream bed scores. Values in bold are significant at the Bonferroni corrected level of α = 0.002

	Percent EPT	Percent insects	Total inds	Species richness	SHMAK invert score	SHMAK stream bed	SHMAK bank vegetation
Percent EPT	1.00						
Percent insects	0.86	1.00					
Total inds	-0.17	-0.12	1.00				
Species richness	0.13	0.14	0.35	1.00			
SHMAK invert score	0.76	0.84	0.14	0.57	1.00		
SHMAK stream bed	0.67	0.68	0.07	0.28	0.73	1.00	
SHMAK bank vegetation	0.68	0.84	0.02	0.07	0.66	0.50	1.00

Multivariate invertebrate community analysis in sheep/beef farms

The overall invertebrate community composition at up and downstream sites on Organic, IM and Conventional sheep/beef farms was compared using discriminant function analysis. The sites were classified into six *a priori* groups: SA_UP = upstream sites on Organic farms, SA_DOWN = downstream sites on Organic, SB_UP = upstream on IM farms, SB_DOWN = downstream sites on IM farms, SC_UP = upstream sites on Conventional farms, and SC_DOWN = downstream sites on Conventional farms (Figure 7). Individual sites to the left of Axis 1 have higher abundances of flatworm, ostracod, and snail 2, while those to the right of Axis 1 have higher rough and smooth cased caddis. Sites lower on axis 2 have more midges, snail 2 and oligochaete worms, while those higher up on axis 2 have more flatworms, mayflies, ostracods and snail 1 (Table 22). The analysis only placed sites in their correct group 46.2 % (n = 52) of the time, and was most accurate for upstream sites on Conventional farms (sites correctly classified 87.5 % of the time, n = 8), and least accurate for upstream sites on Organic and IM farms, only correctly classifying 22.2 % of sites in both cases (n = 9 for each). There were no significant differences in multivariate group means for each of the six sites (MANOVA Pillai-Bartlett trace = 1.01, Approximate χ^2 = 50.90, df = 55., P = 0.632), nor were there any significant univariate differences in abundance between sites for individual taxa.

The differences in invertebrate community composition were also tested between panels using a multivariate analysis of variance (MANOVA). Once cluster effects were controlled for, there were no significant differences in overall community composition between Organic, IM and Conventional sheep/beef farms (up and downstream sites pooled: Pillai-Bartlett trace = 0.74, Approximate χ^2 = 30.86, d.f = 24, p = 0.158). Of the univariate tests for significant differences between panels for individual taxa when cluster effects were controlled for, there were significantly more bivalves on organic farms than on either IM or Conventional farms (Panel means ± standard error with sites pooled: Organic = 7.17 ± 2.64 individuals per site, IM = 2.39 ± 1.41 individuals per site, and Conventional = 1.69 ± 0.92 individuals per site, $F_{2,38}$ = 3.65, P = 0.036), and significantly more worms on IM sheep/beef farms than on Organic or Conventional farms (panel mean totals with sites pooled: Organic = 44.67 ± 15.41 individuals per site, IM = 75.83 ± 25.36 individuals per site, and Conventional = 13.13 ± 7.83 individuals per site, $F_{2,38}$ = 3.61, P = 0.037).

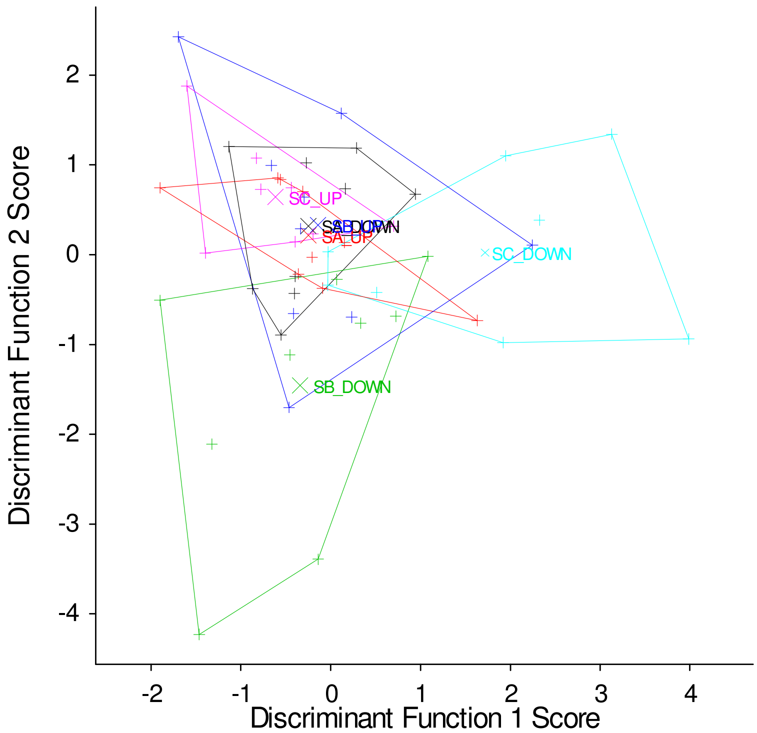

Figure 7: DFA Scores for all up and down stream sites with water on sheep/beef farms. SA_UP = upstream sites on Organic farms, SA_DOWN = downstream sites on Organic, SB_UP = upstream on IM farms, SB_DOWN = downstream sites on IM farms, SC_UP = upstream sites on Conventional farms, and SC_DOWN = downstream sites on Conventional farms. Taxa included in the analysis were beetle, cranefly, crustacean, flatworm, mayfly, midge, ostracod, rough cased caddis, smooth cased caddis, snail 1, snail 2 and oligochaete worms. Polygons enclose all values for a particular group.

Table 22: Discriminant function scores for individual taxa at up and down stream sites on ARGOS organic, IM and conventional sheep/beef farms. At each site, 10 medium sized cobbles (12 – 20 cm diameter) were examined and all individual invertebrates were identified and counted. Values used in the analysis were total values for each site.

Taxa	DF1	DF 2	DF 3	DF4	DF5
Beetle	-0.3661	-0.0467	-0.0020	-0.5995	0.4133
Flatworm	-0.0139	0.0170	-0.0116	0.0096	0.0172
Mayfly	-0.0246	0.0201	-0.0184	-0.0262	0.0025
Midge	-0.0103	-0.0086	0.0001	-0.0019	0.0042
Ostracod	-0.0102	0.0020	-0.0024	0.0008	-0.0059
Rough cased caddis	0.0405	0.0023	0.0128	0.0215	-0.0844
Smooth cased caddis	0.0160	-0.0024	-0.0292	-0.0133	0.0199
Snail 1	-0.0137	0.0067	-0.0027	0.0093	-0.0092
Snail 2	-0.0170	-0.0211	0.0194	0.0127	-0.0274
Oligochaete worm	-0.0041	-0.0071	-0.0088	0.0003	-0.0014

There were also no significant differences between the six groups in their SHMAK invertebrate scores (Average ± standard error: SA_UP = 3.85 ± 0.71, SA_DOWN = 3.75 ± 0.55, SB_UP = 3.70 ± 0.81, SB_DOWN = 2.68 ± 0.52, SC_UP = 3.16 ± 0.60, SC_DOWN = 3.71 ± 0.83; $F_{5,46}$ = 0.55, P = 0.74).

Invertebrates in dairy farms

SHMAK scores

The average scores for individual SHMAK assessment scores and the overall SHMAK score on organic conversion and conventional dairy farms are shown in Table 23. There were greater increases in SHMAK invertebrate score on conventional dairy farms than on organic conversion farms, although these differences were not significant, either when all farms with water were included ($F_{1,13}$ = 3.01, P = 0.106), or when farms with water were blocked by cluster ($F_{1,4}$ = 2.56, P = 0.185).

The average values for different univariate macro-invertebrate community indices in each panel are shown in Table 24. There were no significant differences between the panels in any of the univariate community indices, and there were no significant differences in the univariate metrics between the four site groups (up and down stream sites in each panel).

The correlations between univariate macro-invertebrate community indices and the SHMAK invertebrate, riparian vegetation and stream bed score are shown in Table 25. There were significant positive correlations between the average percent EPT for a farm and the average percent insects and SHMAK bank vegetation score. There were also significant positive correlations between the average percent insects for a farm and both the SHMAK stream bed and bank vegetation scores.

Table 23: Average values for overall SHMAK scores and individual components on ARGOS organic conversion and conventional dairy farms. All farms with running water were included in the analyses with no blocking, while only farms from Clusters 4, 6, 7, 9, and 11 were used in the blocked analysis.

Variable	n	Organic conversion mean	Organic conversion SE	n	Conventional mean	Conventional SE
Percent invertebrate change No blocking	10	-5.59	9.58	9	28.07	18.55
Percent invertebrate change Blocking	5	2.9	11.19	5	33.11	28.13
Percent periphyton change No blocking	10	-13.28	48.93	9	15.47	46.22
Percent periphyton change Blocking	4	5.28	58.45	4	29.76	56.75
Percent SHMAk change No blocking	7	41.55	29.46	8	42.08	29.83
Percent SHMAk change Blocking	5	33.17	31.56	5	37.33	41.56
Bank vegetation average No blocking	10	-5.91	1.06	9	-5.87	0.87
Bank vegetation average Blocking	5	-6.22	1.62	5	-4.83	1.35

Table 24: Univariate macro-invertebrate community indices from ARGOS dairy farms. Percent insects indicates what proportion of the total invertebrates recorded were insects, and percent EPT refers to the proportion of total invertebrates that were Ephemeroptera (mayflies), Plecoptera (stoneflies) and Trichoptera (caddisflies). For an explanation of the SHMAK invert score, see Table 1.

Panel		Total individuals	Species richness	Percent insects	Percent EPT	SHMAK invert score
Converting organic	Mean	84.5	6.4	24.5	27.1	3.57
	Standard deviation	67.1	2	21.6	22.9	0.87
	%CV	79.2	31.2	88.3	84.4	24.37
Conventional	Mean	110.4	5.6	17.3	18.4	3.01
	Standard deviation	85.9	2.3	23.4	18.9	1.86
	%CV	77.8	40.5	134.9	102.8	61.79
Difference		No	No	No	No	No

Table 25: Pearsons Correlation coefficents for the relationships on ARGOS dairy farms between average values for each univariate macro-invertebrate community index on each farm and the average values for the SHMAK invertebrate, bank vegetation, and stream bed scores. Values in bold are significant at the Bonferroni corrected level of $\alpha = 0.002$

	Percent EPT	Percent insects	Total individuals	Species richness	SHMAK invert score	SHMAK stream bed	SHMAK bank vegetation
Percent EPT	1.00						
Percent insects	0.86	1.00					
Total inds	0.02	0.28	1.00				
Species richness	-0.05	0.09	0.51	1.00			
SHMAK invert score	0.19	0.49	-0.04	0.24	1.00		
SHMAK stream bed	0.52	0.77	0.11	-0.01	0.63	1.00	
SHMAK bank vegetation	0.80	0.78	0.17	-0.21	0.20	0.41	1.00

Multivariate invertebrate community analysis

The overall invertebrate community composition at up and downstream sites on Organic Conversion and Conventional dairy farms was compared using discriminant function analysis, where sites were classified into up four groups; DA_UP = upstream on Organic Conversion dairy farms, DA_DOWN = downstream sites on Organic Conversion farms, DC_UP = upstream sites on Conventional dairy farms, and DC_DOWN = downstream sites on Conventional dairy farms (Figure 8). Overall, organic conversion farms tend to have higher abundances of ostracods and snail 1, and lower abundances of beetles, mayflies and snail 2 than conventional dairy farms. Within organic conversion farms, crustaceans, midges, ostracods and worms had higher relative abundances at downstream sites, while the reverse pattern applied in conventional dairy farms (see Table 26). The analysis placed sites in their correct group 76.7 % (n = 30) of the time, and was most accurate for downstream sites on Conventional farms (sites correctly classified 100 % of the time, n = 8), and least accurate for upstream sites on Conventional farms, correctly classifying 62.5 % of sites (n = 8).

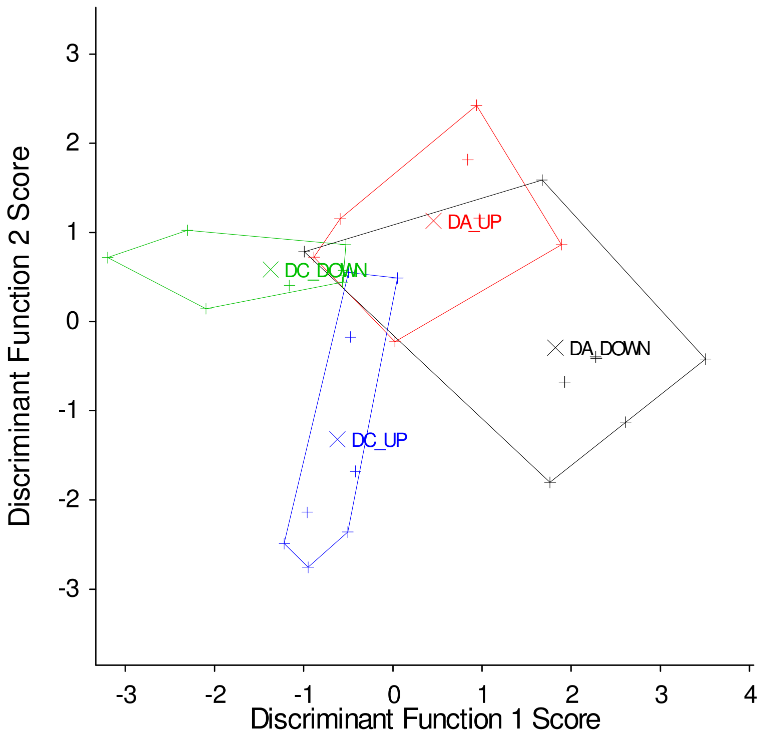

Figure 8: Discriminant Function Analysis Scores for all up and down stream sites with water on dairy farms. DC_UP = upstream sites on Conventional dairy farms, DC_DOWN = downstream sites on Conventional, DA_UP = upstream on Organic Conversion dairy farms, and DA_DOWN = downstream sites on Organic Conversion farms. Taxa included in the analysis were beetle, crustacean, flatworm, mayfly, midge, ostracod, rough cased caddis, smooth cased caddis, snail 1, snail 2 and oligochaete worms. Polygons enclose all values for a particular group.

There were no significant differences in multivariate group means for each of the four sites (Pillai-Bartlett trace = 1.31, Approximate χ^2 = 40.37, d.f = 33, P = 0.177), nor were there any significant univariate differences in abundance between sites for individual taxa.

The differences in invertebrate community composition were also tested between panels. Once cluster effects were controlled for, there were no significant differences in overall community composition between Organic Conversion and Conventional dairy farms (up and downstream sites pooled: Pillai-Bartlett trace = 0.76, Approximate χ^2 = 9.14, df = 11, P = 0.609), or between up and downstream sites (Panels pooled: Pillai-Bartlett trace = 0.65, Approximate χ^2 = 6.82, df = 11, P = 0.814). There was also no significant panel by site interaction in overall community composition (Pillai-Bartlett trace = 0.61, Approximate χ^2 = 6.19, d.f. = 11, P = 0.861). There were no significant difference between sites or panels for individual taxa when cluster effects were controlled for, although the difference in total mayfly abundance between panels approached significance (Sites pooled: Mean totals ± standard error: organic conversion = 0.93 ± 0.31 individuals per survey, conventional = 9.38 ± 4.91, $F_{1,12}$ = 4.44, P = 0.057).

There were also no significant differences between the four groups in their SHMAK invertebrate scores (Average ± standard error: DA_UP = 3.74 ± 0.37, DA_DOWN = 3.41 ± 0.30, DC_UP = 3.01 ± 0.66, DC_DOWN = 3.68 ± 0.68; $F_{3,26}$ = 0.31, P = 0.82).

Table 26: Discriminant function scores for individual taxa at up and down stream sites on ARGOS organic conversion and conventional dairy farms. At each site, 10 medium sized cobbles (12 – 20 cm diameter) were examined and all individual invertebrates were identified and counted. Values used in the analysis were total values for each site.

Taxa	DF1	DF 2	DF 3
Beetle	-0.23	0.02	-0.29
Crustacean	-0.09	-0.19	-0.14
Flatworm	0.08	0.22	0.29
Mayfly	-0.22	-0.09	-0.19
Midge	-0.01	-0.44	0.26
Ostracod	0.22	-0.32	-0.22
Rough cased caddis	-0.12	0.06	-0.49
Smooth cased caddis	0.06	-0.02	0.03
Snail 1	0.13	-0.002	0.24
Snail 2	-0.20	-0.01	-0.22
Oligochaete worm	-0.10	-0.37	0.27

Periphyton in sheep/beef farms

SHMAK scores

The average SHMAK periphyton scores for Organic, IM and Conventional sheep/beef farms are shown in Table 19. On average, both Organic and IM sheep/beef farms had decreases in SHMAK periphyton scores, while Conventional farms had increases in periphyton scores. However, there was no significant difference in the percentage change in periphyton score between the three panels, either when all farms with water were included ($F_{2,16}$ = 2.25, P = 0.138), or when farms with water were blocked by cluster ($F_{2,7}$ = 1.30, P = 0.330).

Multivariate periphyton community analysis

The overall periphyton community composition at up and downstream sites on Organic, IM and Conventional sheep/beef farms was compared using discriminant function analysis. The sites were classified into six groups; SA_UP = upstream sites on Organic farms, SA_DOWN = downstream sites on Organic, SB_UP = upstream on IM farms, SB_DOWN = downstream sites on IM farms, SC_UP = upstream sites on Conventional farms, and SC_DOWN = downstream sites on Conventional farms (Figure 9). The analysis placed sites in their correct group 38.5 % (n = 52) of the time, and was most accurate for downstream sites on Organic farms (sites correctly classified 66.6 % of the time, n = 9), and least accurate for upstream sites on Organic, only correctly classifying 11.1 % of sites (n = 9).

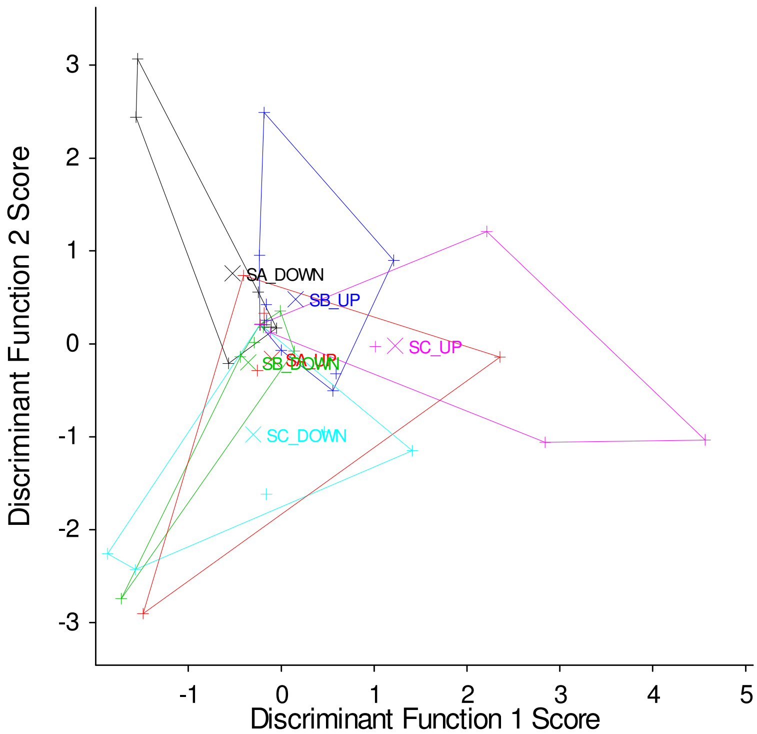

Figure 9: DFA Scores for analysis of periphyton communities all up and down stream sites with water on sheep/beef farms. SA_UP = upstream sites on Organic farms, SA_DOWN = downstream sites on Organic, SB_UP = upstream on IM farms, SB_DOWN = downstream sites on IM farms, SC_UP = upstream sites on Conventional farms, and SC_DOWN = downstream sites on Conventional farms. Morphotaxa included in the analysis were long green filamentous, medium brown, medium green, thick green, thin black, thin green and thin light brown algae. Polygons enclose all values for a particular group.

Sites negatively associated with Axis 1 had higher average percentage cover of long green filamentous, medium green and thin light brown algae, while sites that were positively associated with Axis 1 had more medium brown, thick green, thin black and thin green algae. Sites negatively associated with Axis 2 have more long green filamentous, medium green, thin black and thin green algae (Table 27).

Table 27: Discriminant function scores for periphyton taxa at all up and downstream sites on ARGOS organic, IM and conventional sheep/beef farms. For each site, either 10 medium sized cobbles (6-12 cm diameter), or 10 substrate samples collected in a 10 cm sieve were examined, and the percentage cover of each periphyton taxa was recorded.

Taxa	DF1	DF2
Long green filament	-0.14	-0.17
Brown medium	0.10	-0.01
Green medium	-0.17	-0.33
Thick green	0.07	0.05
Thin black	0.12	-0.03
Thin green	0.08	-0.06
Thin light brown	-0.01	0.23

There were no significant differences in multivariate group means for each of the six sites (Pillai-Bartlett trace = 0.77, Approximate χ^2 = 38.39, d.f. = 35, P = 0.319), nor were there any significant univariate differences in abundance between sites for individual taxa.
The differences in periphyton community composition were also tested between panels. Once cluster effects were controlled for, there were no significant differences in overall community composition between Organic, IM and Conventional sheep/beef farms (up and downstream sites pooled Pillai-Bartlett trace = 0.44, Approximate χ^2 = 17.41, d.f. = 14, P = 0.235; Table 19). Of the univariate tests for significant differences between panels for individual taxa when cluster effects were controlled for, there was significantly more thin black algae on Conventional farms than on either organic farms or IM farms (Panel means ± standard error with sites pooled: Organic = 0.31 ± 0.21 % average cover, IM = 0.06 ± 0.06 % cover, and Conventional = 2.0 ± 2.0 % cover, $F_{2,38}$ = 3.57, P = 0.038).

There were also no significant differences between the six groups in their SHMAK periphyton scores (Average ± standard error: SA_UP = 2.69 ± 0.84, SA_DOWN = 2.47 ±0.89, SB_UP = 4.40 ± 0.77, SB_DOWN = 2.42 ± 0.95, SC_UP = 4.32 ± 1.35, SC_DOWN = 3.60 ± 1.13; $F_{5,40}$ = 1.03, P = 0.42).

Periphyton in dairy farms

SHMAK scores

The average SHMAK periphyton scores on organic conversion and conventional dairy farms are shown in Table 23. There were greater changes in SHMAK periphyton score on Conventional dairy farms than on Organic Conversion farms, although these differences were not significant, either when all farms with water were included ($F_{1,8}$ = 0.34, P = 0.575), or when farms with water were blocked by cluster ($F_{1,2}$ = 0.66, P = 0.502).

Multivariate periphyton community analysis

The overall periphyton community composition at up and downstream sites on Organic Conversion and Conventional dairy farms was compared using discriminant function analysis, where sites were classified into up four groups; DA_UP = upstream on organic conversion dairy farms, DA_DOWN = downstream sites on Organic Conversion farms, DC_UP = upstream sites on Conventional dairy farms, and DC_DOWN = downstream sites on Conventional dairy farms (Figure 10). The analysis placed sites in their correct group 50.0 % (n = 30) of the time, and was most accurate for upstream sites on Conventional farms (sites correctly classified 75.0 % of the time, n = 8), and least accurate for downstream sites on Conventional sites, only correctly classifying 12.5 % of sites (n = 8).

Sites negatively associated with Axis 1 had greater average abundances of brown and green filamentous algae and long brown filamentous algae, while sites that are positively associated with Axis 1 had higher abundances of black, green and light brown thin algae. Sites negatively associated with Axis 2 have more thin algae and more brown filamentous algae, while sites positively associated with Axis 2 have more green filamentous and long green and long brown filamentous algae. Long filamentous algae appear to be associated with down stream sites with green and long brown more common on Conventional farms and long green on Organic Conversion farms. Upstream sites appear to be more commonly associated with black, green and light brown thin algae (Table 28). There were no significant differences in multivariate group means for each of the four sites (Pillai-Bartlett trace = 0.78, Approximate χ^2 = 22.78, d.f = 22, P = 0.356), nor were there any significant univariate differences in abundance between sites for individual taxa.

The differences in periphyton community composition were also tested between panels. Once cluster effects were controlled for, there were no significant differences in overall community composition between organic conversion and conventional dairy farms (up and downstream sites pooled: Pillai-Bartlett trace = 0.43, Approximate χ^2 = 4.73, d.f. = 7. P = 0.693), or between up and downstream sites (Panels pooled: Pillai-Bartlett trace = 0.62, Approximate χ^2 = 8.06, d.f. = 7, P = 0.327). There was also no significant panel by site interaction in overall community composition (Pillai-Bartlett trace = 0.23, Approximate χ^2 = 2.90, d.f. = 7, P = 0.894). There were no significant difference between sites or panels for individual taxa when cluster effects were controlled for, although the difference in percentage cover of brown filamentous algae between up and down stream sites approached significance (Panels pooled: organic conversion mean percentage cover = 0.02 %, conventional = 1.7 %, $F_{1,12}$ = 4.5, P = 0.055).

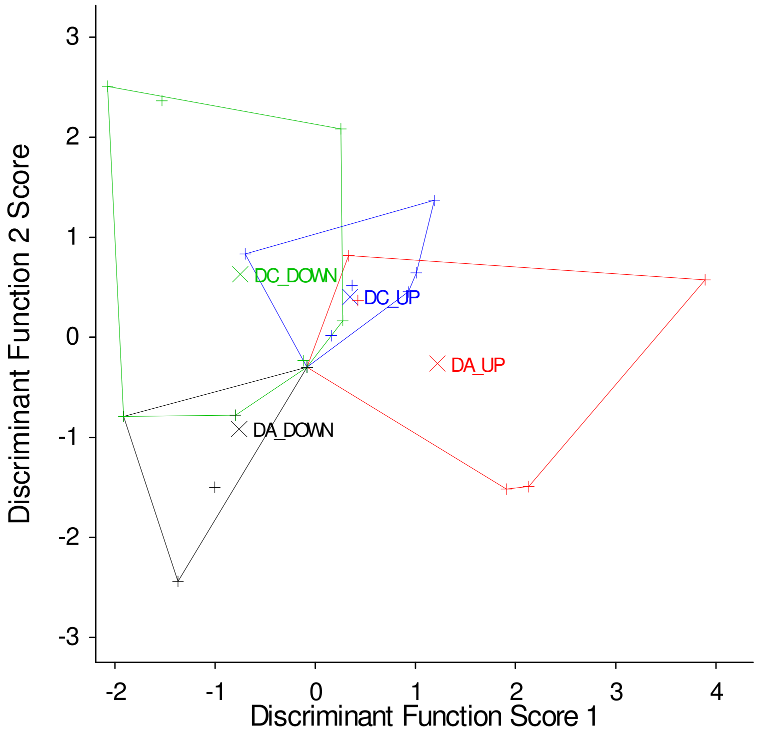

Figure 10: DFA Scores for periphyton communities on all up and down stream sites with water on dairy farms. DC_UP = upstream sites on Conventional dairy farms, DC_DOWN = downstream sites on Conventional, DA_UP = upstream on Organic Conversion dairy farms, and DA_DOWN = downstream sites on Organic Conversion farms. Morphotaxa included in the analysis were brown filamentous, green filamentous, long brown filamentous, long green filamentous, thin black, thin green and thin light brown algae. Polygons enclose all values for a particular group.

Table 28: Discriminant function scores for periphyton taxa at all up and downstream sites on ARGOS converting organic and conventional dairy farms. For each site either 10 medium sized cobbles (6-12 cm diameter), or 10 substrate samples collected in a 10cm sieve were examined, and the percentage cover of each periphyton taxa was recorded.

Scores	DF1	DF2
Brown filament	-0.62	-0.20
Green filament	-0.24	0.33
Long brown filament	-0.04	0.07
Long green filament	0.01	0.02
Thin black	0.12	-0.04
Thin green	0.63	0.19
Thin light brown	-0.18	-0.12

There were also no significant differences between the four groups in their SHMAK periphyton scores (Average ± standard error: DA_UP = 3.33 ± 1.40, DA_DOWN = 2.18 ±1.24, DC_UP = 1.99 ± 0.88, DC_DOWN = 1.94 ± 0.55; $F_{3,25}$ = 0.40, P = 0.75)

Vegetation in sheep/beef farms

SHMAK scores

The average SHMAK bank vegetation scores on Organic, IM and Conventional sheep/beef farms are shown in Table 19. The average bank vegetation score was highest (indicating better quality under the SHMAK rating) on Conventional sheep/beef farms than on either Organic or IM farms, although these differences were not significant, either when all farms with stream channels were included ($F_{2,35}$ = 0.35, P = 0.707), or when farms with stream channels were blocked by cluster ($F_{2,14}$ = 0.77, P = 0.481).

Multivariate riparian vegetation analysis

The overall riparian vegetation on Organic, IM and Conventional sheep beef farms was compared using a principle components analysis. For each farm, the average percentage cover of trees (native and introduced pooled), scrub (native or introduced), tussock, pasture and bare ground across the 10 survey sites on each stream was calculated. The results of the PCA are shown in Figure 11 and Table 29. PCA Axis 1 explained 40.9 % of the variation, while PCA Axis 2 explained a further 29.3 % of the variation.
Sites negatively associated with Axis 1 had greater percentage coverage of pasture in the riparian zone, while sites positively associated with Axis 1 had greater percentage coverage of trees and scrub. Sites negatively associated with Axis 2 had greater percentage coverage of bare ground and trees, while sites positively associated with Axis 2 had greater percentage coverage of scrub and tussock.

There were no significant differences in the overall riparian vegetation cover between panels when cluster effects were controlled for, either for PCA Axis 1 ($F_{2,16}$ = 2.0, P = 0.168 Averages ± standard error: Organic = 0.23 ± 0.33, IM = -0.32 ± 0.19, Conventional = 0.90 ± 0.75), or PCA

Axis 2 ($F_{2,16}$ = 1.48, P = 0.258 Averages ± standard error: Organic = 0.08 ± 0.49, IM = 0.35 ± 0.56, Conventional = -0.40 ± 0.21).

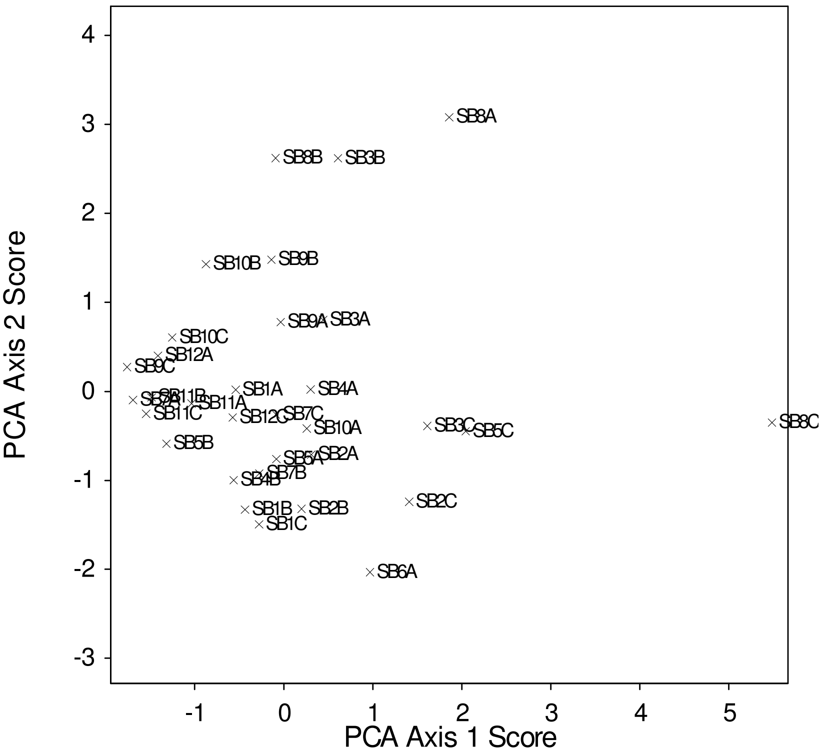

Figure 11: PCA of average percentage cover of different vegetation classes on ARGOS sheep/beef farms (correlation matrix). Variables used are Average percentage cover of trees, scrub, tussock, pasture, and bare ground.

Table 29: PCA Axis scores for riparian vegetation surveyed on each ARGOS sheep/beef property. A correlation matrix was used for the analysis.

Variable	PCA Axis 1	PCA Axis 2
Bare ground	0.23	-0.57
Pasture	-0.66	-0.12
Scrub	0.56	0.24
Tree	0.45	-0.21
Tussock	0.02	0.75

The correlations between the percentage cover for each of the vegetation classes on the ARGOS sheep/beef farms are shown in Table 30. There was a significant positive correlation between the SHMAK bank vegetation score and the percentage cover of scrub, tussock and trees, reflecting the high weighting these categories are given in the SHMAK assessment. There were also a negative correlation between the percentage cover of tussock and bare ground; although this was not significant once the Bonferroni correction was applied.

Table 30: Correlations between percentage cover of vegetation classes in riparian zones on all ARGOS dairy farms with stream channels. Figures in bold are significant at the Bonferroni corrected level of 0.004.

	Scrub	**Bare ground**	**Tussock**	**Tree**	**Bankveg**
Scrub	1				
Bare ground	0.03	1			
Tussock	0.17	-0.38	1		
Tree	0.24	0.02	-0.24	1	
Bank vegetation	0.66	-0.16	0.41	0.57	1

Vegetation in dairy farms

SHMAK scores

The average SHMAK bank vegetation scores on organic conversion and conventional dairy farms are shown in Table 23. The average bank vegetation score was higher (indicating better quality under the SHMAK rating) on Conventional dairy farms than on Organic Conversion farms, although these differences were not significant, either when all farms with stream channels were included ($F_{1,17}$ = 0.00, P = 0.977), or when farms with stream channels were blocked by cluster ($F_{1,4}$ = 0.61, P = 0.478).

Multivariate riparian vegetation analysis

The overall riparian vegetation on converting organic and conventional dairy farms was compared using a principle components analysis. For each farm, the average percentage cover of trees (native and introduced pooled), scrub (native or introduced), tussock, pasture and bare ground across the 10 survey sites on each stream was calculated. The results of the PCA are shown in Figure 12 and Table 31. PCA Axis 1 explained 48.9% of the variation, while PCA Axis 2 explained a further 25.7% of the variation.
Sites negatively associated with Axis 1 had greater percentage coverage of pasture in the riparian zone, while sites positively associated with Axis 1 had greater percentage coverage of trees and scrub. Sites negatively associated with Axis 2 had greater percentage coverage of bare ground and tussock, while sites positively associated with Axis 2 had greater percentage coverage of trees.

There were no significant differences in the overall riparian vegetation cover between panels when cluster effects were controlled for PCA Axis 1 ($F_{1,5}$ = 1.45, P = 0.282 Averages ± standard error: Organic Conversion = -0.10 ± 0.76, Conventional = 0.79 ± 0.68). However, Organic Conversion dairy farms had significantly higher PCA Axis 2 scores than Conventional farms, once cluster effects were controlled for ($F_{1,5}$ = 6.52, P = 0.05 Averages ± standard error: Organic Conversion= 0.45 ± 0.34, Conventional = -0.55 ± 0.36), suggesting that Converting organic dairy farms in the ARGOS study have significantly more trees and tussock, and less bare ground than Conventional dairy farms

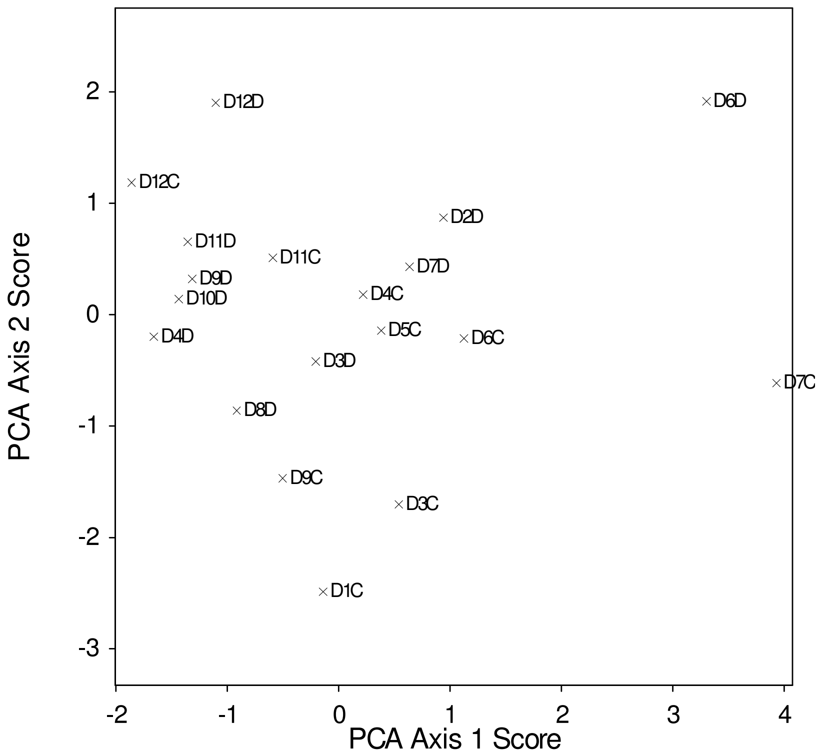

Figure 12: PCA of average percentage cover of different vegetation classes on ARGOS dairy farms (correlation matrix). Variables used are average percentage cover of trees, scrub, tussock, pasture, and bare ground.

Table 31: PCA Axis scores for each surveyed stream. A correlation matrix was used for the analysis.

Variable	PCA Axis 1	PCA Axis 2
Bare ground	0.12	-0.76
Pasture	-0.62	0.12
Scrub	0.59	0.01
Tree	0.49	0.46
Tussock	0.15	-0.45

Table 32: Correlations between percentage cover of vegetation classes in riparian zones on all ARGOS dairy farms with stream channels. Figures in bold are significant at the Bonferroni corrected level of 0.004.

	Scrub	Bare ground	Tussock	Tree	Bank vegetation score
Scrub	1				
Bare ground	0.15	1			
Tussock	0.12	0.13	1		
Tree	0.59	-0.26	-0.01	1	
Bank vegetation score	0.59	-0.18	0.17	0.91	1

The correlations between the percentage cover for each of the vegetation classes on the ARGOS dairy farms are shown in Table 32. There was a significant positive correlation between the SHMAK bank vegetation score and the average percentage cover of trees, reflecting the high weighting trees are given in the SHMAK assessment. There were also positive correlations between the bank vegetation score and the percentage cover of scrub, and between coverage of trees and shrubs, although neither of these was significant once the Bonferroni correction was applied.

3.4 Predicting water quality change on ARGOS sheep/beef farms

The results of the best subsets GLM model selection are shown for multivariate indicators of water quality and nutrient loading in Table 33, and for individual univariate parameters in Table 34. The candidate explanatory variables were able to predict overall changes in water clarity on PCA Axis 1, but not PCA Axis 2. There was a significant positive relationship between bank vegetation value and PCA Axis 1; that is sites with better bank vegetation (and better streambed scores $r = 0.44$, $P = 0.009$), have relatively more sediment deposition and greater increases in clarity. There was a weakly negative relationship between stream bed value and PCA Axis 1, so that sites with more sediment had greater increases in clarity and sediment, although this may be an effect rather than a cause.

The model for predicting overall nutrient change (Nutrient PCA Axis 1) was significant, and explained 84.8 % of the variation. Sites positively associated with PCA Axis 1 have relatively greater increases in P (DRP and TP) and NH_4^+ and relatively smaller increases in TOC and NO_2 + NO_3. The reverse holds for sites negatively associated with the Axis. There was a significant panel effect in the model, with IM farms having relatively greater increases in TOC and NO_2 + NO_3 than Organic farms, while Conventional farms had relatively greater increases in P and NH_4^+ than Organic farms. There were significant positive relationships between both the stock access value and the stock presence value and Axis 1; i.e. farms with more stock entering stream had relatively greater increases in TOC and NO_2 + NO_3.

Of the univariate response variables (Table 34), the explanatory variables were able to significantly predict the percentage change in NO_2 + NO_3, with the model explaining 66 % of the variance. There was a significant negative relationship between the stock presence value and percentage change in NO_2 + NO_3; that is, sites with more stock in the stream have greater percent increases in NO_2 + NO_3. There was also a negative relationship between the stream bed value and percentage change, with sites with more complex stream beds had smaller percent increases in NO_2 + NO_3.

The model for predicting percent change in NH_4^+ was significant, with 41.8 % of the variance explained. The bank vegetation score was positively related to the percentage change in NH_4^+, suggesting that more complex bank vegetation is less effective at filtering NH_4^+ from the surrounding paddocks (either from Urea or urine patches).

The model for predicting percent change in DRP was significant, although the variance explained was only 34.8 %. The bank vegetation score was negatively related to percentage change in DRP; i.e. less complex vegetation, results in more DRP in the stream. There was also a positive relationship between stock access and percent DRP change, with less stock in the channel gave greater increases in DRP

The model for predicting percent change in total phosphorous (TP) was also significant, although again the variance explained by the model was low at 25.6 %. There was a significant relationship between stock access and percent change in TP, with less stock access leads to greater percent increases in TP.

The model for predicting percent change in total sediment was significant (variance explained = 33.4 %). The only significant predictor was the bank vegetation score, with a significant positive relationship between the bank vegetation score and percentage increase in total sediment.

Generalized linear models using individual vegetation components in sheep/beef farms

The models that contained the SHMAK bank vegetation score as a significant predictor were re-run using the un-weighted estimates of riparian vegetation cover (vegetation PCA scores) and the individual component scores, to identify exactly which components of the vegetation were driving the observed relationships. This permitted both a validation of the SHMAK bank vegetation score, and also allowed us to identify the specific vegetation classes that could be managed by farmers to achieve desired waterway management outcomes. The results of these models are shown in Table 35.

For the multivariate water quality analysis (Clarity PCA Axis 1), there were negative relationships between the Vegetation PCA Axis 1 and Axis 2 and the Clarity PCA Axis 1. For vegetation PCA Axis 1, this means that sites with more scrub and trees had relatively smaller increases in organic and total sediment and smaller increases in the clarity tube reading, while for Vegetation PCA Axis 2, sites with relatively more scrub and tussock had smaller increases in sediment and clarity tube readings. The model using just the individual vegetation cover classes highlighted percent bare ground, scrub and tussock as the significant variables affecting Clarity PCA Axis 1 (Table 35). In all cases, sites with relatively more bare ground, scrub or tussock had relatively smaller increases in organic and total sediment and smaller increases in the clarity tube reading.

For the relationship between riparian vegetation and percent change in NH_4^+, the model using the vegetation PCA axes had a significant positive relationship between vegetation PCA Axis 1 scores and percent increase in NH_4^+ across the farm. This suggests sites with more scrub and trees, and less pasture and tussock had larger increases in NH_4^+. From the model using vegetation components, it is clear that the important significant predictors are pasture and tussock cover; with significant relationships between increasing pasture and tussock cover and smaller relative increases in NH_4^+.

For the relationship between riparian vegetation and percent change in DRP, the model using vegetation PCA axes was not significant. From the model using vegetation components, the significant predictors are tussock and trees, with higher cover of both leading to smaller increases in DRP.

Finally, for the relationship between riparian vegetation and percent change in total sediment, the model using vegetation PCA axes had significant positive relationships between vegetation PCA axis scores and percent increase in total sediment across the farm. For PCA Axis 1 this means sites with more scrub and trees have more sediment accumulated across the farm, and for Axis 2, sites with more scrub and tussock had greater increases in sediment across the farm. For the individual components, there was a significant negative relationship between pasture and relative increases in total sediment, and a significant positive relationship between tussock cover and relative total sediment increase, with sites with less pasture and more tussock having greater relative increases in total sediment.

Table 33: Results of Generalized linear models run to predict percent change in multivariate indicators of water clarity and quality on ARGOS sheep/beef farms. Shown are the best models from an all-subsets model selection procedure using an *a priori* set of potential predictor variables. The predictor variables used were Panel (Organic, IM or Conventional), SHMAK bank vegetation score, Fencing value, Stock access score, Stock presence score, and SHMAK stream bed score; for an explanation of the variables, see the text. For each response variable, the best model was selected using Akiake's Information Criterion, and is shown along with the percent of the variance explained by the model (R^2), the significance test and P value for the model, as well as the estimates and standard errors for the partial regression slopes for each parameter in the model, and the Student's t statistic for each parameter. ns = not significant, * = P < 0.10, ** = P < 0.05, *** = P < 0.01.

Response Variable	Best model	R^2	Significance test	P value	Parameters	Parameter estimates (s.e.)	Students t
Percent change in shmak score	Constant + Panel	9.8	$F_{2,23} = 2.36$	0.116	Constant	9.1 (33)	0.28^{ns}
					Panel – IM	-22.1 (46.6)	-0.47^{ns}
					Panel - Conventional	78.2 (48.1)	1.63^{ns}
Clarity PCA Axis 1	Constant + Bank vegetation + Fencing + Stream bed	51.5	$F_{3,10} = 5.60$	0.016	Constant	0.47 (0.42)	1.05^{ns}
					Bank vegetation	0.25 (0.07)	3.46^{***}
					Fencing	0.13 (0.08)	1.62^{ns}
					Stream bed	-0.08 (0.03)	-2.74^{**}
Clarity PCA Axis 2	Constant + Bank vegetation	0.7	$F_{1,12} = 1.10$	0.316	Constant	-0.44 (0.45)	-0.87^{ns}
					Bank vegetation	-0.09 (0.09)	-1.05^{ns}
Nutrient PCA Axis 1	Constant + Stock presence	0.0	$F_{1,10} = 0.92$	0.360	Constant	-0.73 (0.86)	-0.84^{ns}
					Stock presence	0.12 (0.12)	0.96^{ns}
Nutrient PCA Axis 2	Constant + Stock access + Stock presence + Stream bed	42.7	$F_{3,8} = 3.73$	0.061	Constant	0.24 (0.52)	0.45^{ns}
					Stock access	-0.39 (0.12)	-3.22^{**}
					Stock presence	0.21 (0.10)	2.23^{*}
					Stream bed	0.08 (0.04)	2.14^{*}

Table 34: Results of Generalized Linear Models (GLM) run to predict percent change in univariate indicators of water clarity and quality on ARGOS sheep/beef farms. Shown are the best models from an all-subsets model selection procedure using an *a priori* set of potential predictor variables. The predictor variables used were Panel (Organic, IM or Conventional), SHMAK bank vegetation score, Fencing value, Stock access score, Stock presence score, and SHMAK stream bed score; for an explanation of the variables, see the text, and for an explanation of the table headings, see Table 29.

Response Variable	**Best model**	**R^2**	**Significance test**	**P value**	**Parameters**	**Parameter estimates (s.e.)**	**Students t**
Percent temperature change	Constant + Bank vegetation + Stock access	19.9	$F_{2,12} = 2.74$	0.105	Constant Bank vegetation Stock access	26.0 (13.6) 3.54 (2.07) -4.16 (2.30)	1.92^{*} 1.71^{ns} -1.81^{*}
Percent change $NO_2 + NO_3$	Constant + Stock presence + Stream bed	58.7	$F_{2,10} = 9.54$	0.005	Constant Stock presence Stream bed	2656 (667) -385.9 (94.3) -114.5 (43.7)	3.98^{***} -4.09^{***} -2.62^{**}
Percent change NH_4^+	Constant + Bank vegetation	41.8	$F_{1,11} = 9.60$	0.010	Constant Bank vegetation	236.3 (70.0) 32.1 (10.4)	3.37^{***} 3.10^{***}
Percent change DRP	Constant + Bank vegetation + Stock access	32.7	$F_{2,10} = 3.91$	0.056	Constant Bank vegetation Stock access	-1110 (464) -127.9 (46.5) 145.7 (61.1)	-2.39^{**} -2.75^{**} 2.38^{**}
Percent change TOC	Constant + Bank vegetation	0.0	$F_{1,10} = 0.80$	3.92	Constant Bank vegetation	17.9 (21.0) 2.72 (3.05)	0.85^{ns} 0.89^{ns}
Percent change Total P	Constant + Stock access	12.2	$F_{1,11} = 2.67$	0.130	Constant Stock access	-16.7 (31.6) 11.5 (7.04)	-0.53^{ns} 1.64^{ns}
Percent change organic sediment	Constant + Stock access	3.0	$F_{1,15} = 1.50$	0.239	Constant Stock access	-227 (647) 148 (121)	-0.34^{ns} 1.23^{ns}
Percent change Total sediment	Constant + Bank vegetation	33.4	$F_{1,15} = 9.03$	0.009	Constant Bank vegetation	336.0 (96.3) 45.6 (15.2)	3.49^{***} 3.0^{***}
Percent change clarity tube	Constant + Stock access	3.2	$F_{1,17} = 1.60$	0.223	Constant Stock access	-15.7 (46.5) 11.07 (8.75)	-0.34^{ns} 1.26^{ns}

Table 35: Results of Generalized Linear Models (GLM) run to investigate the efficacy of the SHMAK bank vegetation score in predicting percent change in indicators of water clarity and quality on ARGOS sheep/beef farms. For each model that contained the SHMAK bank vegetation score, the model was first run replacing the bank vegetation score with the scores from the vegetation PCA analysis (see Table 25), and is shown as the first model for each response variable. A second analysis was then run, where a best-subsets GLM was performed with the SHMAK bank vegetation score for that site replaced with the average percent cover of bare ground, pasture, scrub, trees and tussock at that site. All parameters that were significant predictors in the original model were retained in the best-subsets analysis, and the model with the lowest AIC value was selected as the best model, and is displayed in the table as the second model for each response variable. For an explanation of the other predictor variables used in the analysis, see the text and Table 29, and for an explanation of the table headings, see Table 29.

Response Variable	Best model	R^2	Significance test	P value	Parameters	Parameter estimates (s.e.)	Students t
Clarity PCA Axis 1	Constant + PCA Axis 1 + PCA Axis 2 + Stock access + Stock presence	37.0	$F_{4,11} = 3.20$	0.057	Constant	0.75 (0.39)	1.93^{*}
					Vegetation PCA Axis 1	-0.42 (0.14)	-3.11^{***}
					Vegetation PCA Axis 2	-0.36 (0.19)	-1.95^{*}
					Fencing	-0.13 (0.09)	-1.43^{ns}
					Stream bed	0.04 (0.03)	1.27^{ns}
Clarity PCA Axis 1	Constant + Bare ground + Scrub + Tussock + Fencing + Stream bed	67.1	$F_{5,10} = 7.31$		Constant	2.41 (0.47)	5.14^{***}
					Bare ground	-0.13 (0.04)	-3.52^{***}
					Scrub	-0.10 (0.03)	-3.36^{***}
					Tussock	-0.34 (0.08)	-4.47^{***}
					Fencing	-0.19 (0.07)	-2.92^{**}
					Stream bed	0.03 (0.02)	1.29^{ns}
Percent change NH_4^+	Constant + PCA Axis 1 + PCA Axis 2	61.3	$F_{2,10} = 10.49$	0.004	Constant	55.0 (33.3)	1.65^{ns}
					Vegetation PCA Axis 1	75.6 (16.9)	4.46^{***}
					Vegetation PCA Axis 2	-35.1 (24.2)	-1.45^{ns}
Percent change NH_4^+	Constant + Pasture + Tussock	64.7	$F_{2,10} = 11.98$	0.002	Constant	504.1 (96.8)	5.21^{***}
					Pasture	-5.98 (1.30)	-4.61^{***}
					Tussock	-29.4 (11.6)	-2.53^{**}
Percent change DRP	Constant + Vegetation PCA Axis 1 + Vegetation PCA Axis 2 +	9.7	$F_{3,9} = 1.43$	0.297	Constant	-118 (285)	-0.41^{ns}

Response Variable	Best model	R^2	Significance test	P value	Parameters	Parameter estimates (s.e.)	Students t
	Stock access						
					Vegetation PCA Axis 1	-146 (116)	-1.26^{ns}
					Vegetation PCA Axis 2	-164 (104)	-1.58^{ns}
					Stock access	104.8 (76.4)	1.37^{ns}
Percent change DRP	Constant + Tussock + Trees + Stock access	41.4	$F_{3,9} = 3.83$	0.051	Constant	277 (191)	1.40^{ns}
					Tussock	-136.5 (49.2)	-2.78^{**}
					Trees	-173.1 (56.8)	-3.15^{**}
					Stock access	163.2 (58.7)	2.78^{**}
Percent change Total sediment	Constant + Vegetation PCA Axis 1 + Vegetation PCA Axis 2	44.4	$F_{2,14} = 7.40$	0.006	Constant	38.8 (46.1)	0.84^{ns}
					Vegetation PCA Axis 1	84.8 (26.5)	3.20^{***}
					Vegetation PCA Axis 2	72.6 (32.1)	2.26^{**}
Percent change Total sediment	Constant + Pasture + Tussock	54.0	$F_{2,11} = 8.62$	0.003	Constant	546 (136)	4.01^{***}
					Pasture	-7.74 (2.01)	-3.85^{***}
					Tussock	21.1 (20.3)	-1.04^{ns}

3.5 Predicting water quality change on ARGOS dairy farms

The results of the best subsets GLM model selection are shown for multivariate indicators of water quality and nutrient loading in Table 36, and for individual univariate parameters in Table 37. The model for predicting overall clarity change on Clarity PCA Axis 1 was significant, and explained 60.4 % of the variance. There was a significant positive relationship between the stock access score and Clarity PCA Axis 1, with sites with less stock in the waterway/riparian area having greater percent increases in sediment levels and water clarity across the farm.

The model for predicting overall clarity change on Clarity PCA Axis 2 was also significant, although the model only explained 35.0 % of the variance. There was a significant negative relationship with the fence value score and PCA Axis 2, indicating sites with more opportunities for stock access into the stream had greater percent increases in organic sediment. There was also a significant positive relationship between the stock access score and PCA Axis 2, that is, sites with more recorded stock access had greater increases in organic sediment.

Of the univariate response variables (Table 37), the explanatory variables were able to significantly predict the percentage change in total phosphorous (TP), although the variance explained was low at 32.6 %. There was a significant negative relationship between bank vegetation value and percentage change in TP; that is, sites with more dense, complex vegetation had relatively smaller increases in TP. There was also a significant positive relationship between the SHMAK stream bed value and percent change in TP, so that sites with more complex substrates and relatively greater increases in TP.

The model for predicting percent change in organic sediment was significant, with 51.2 % of the variance explained. There was a significant positive relationship between the bank vegetation score and percent increase in total organic sediment; that is, sites with more trees and scrub had relatively higher deposition rates of organic sediment. There was also a positive relationship between the stock access score and percent increase in organic sediment; that is, sites with less stock in the channel had relatively greater rates of organic sediment deposition.

The model for predicting percent change in total sediment was also significant (variance explained = 41.2 %). There was a significant positive relationship between stock access and total sediment. As for organic sediment, streams with less stock access into the stream had relatively greater total sediment deposition. There was also a significant positive relationship between the SHMAK stream bed value and percent change in total sediment, so that sites with more complex substrates and relatively greater increases in total sediment.

The model for predicting percent change in *Escherichia coli* was significant, and explained 59.6 % of the variance. Panel was a significant predictor of percent *E. coli* increases, with Conventional farms have significantly greater increases in concentrations that Organic Conversion farms. There was a significant negative relationship between the SHMAK bank vegetation score and percent increases in *E. coli*, so that sites with more complex vegetation (trees and shrubs) had smaller increases in *E. coli*. There was also a significant negative relationship between the stock presence score and percent increases in *E. coli*, that is, sites with more stock in the waterway had relatively larger increases in *E. coli* concentration.

The model for predicting percent change in fecal coliforms was also significant, and explained 59.9 % of the variance. As for *E. coli* concentrations, Panel was a significant predictor of percent coliform increases, with Conventional farms having significantly greater increases in concentrations that Organic conversion farms. There was a significant negative relationship between the SHMAK bank vegetation score and percent increases in coliforms, so that sites with more complex vegetation (trees and shrubs) had smaller increases in coliforms. Finally, there was also a significant negative relationship between the stock presence score and percent increases in coliforms that is, sites with more stock in the waterway had relatively larger increases in coliform concentration.

Generalized linear models using individual vegetation components in dairy farms

The models that contained the SHMAK bank vegetation score as a significant predictor were also re-run for the dairy properties, using the un-weighted estimates of riparian vegetation cover (Vegetation PCA Axis scores) and the individual components, and these results are shown in Table 38.

For the relationship between riparian vegetation and percent change in total phosphorous, the model using the vegetation PCA axes had a significant negative relationship between Vegetation PCA Axis 1 score and percent increase in TP across the farm. This means sites with more pasture (and to a lesser extent bare ground) had relatively greater increases in total phosphorous across the farm. There was also a significant positive relationship between the streambed score and TP increase across the farm. For the analysis using individual vegetation components, there was a significant negative relationship between pasture cover and percent increase in TP, that is sites with more pasture had relatively greater increases in TP.

For the relationship between riparian vegetation and percent change in organic sediment, the model using the vegetation PCA axes had a significant positive relationship between Vegetation PCA Axis 1 score and percent increase in organic sediment across the farm. Sites with more scrub and trees had bigger increases in organic sediment across the farm. For the analysis using the individual components, there were significant negative relationships between pasture and scrub and percent change in organic sediment; so that sites with more pasture and scrub had relatively smaller increases in organic sediment across the farm. There was also a significant positive relationship between stock presence score and percent increase in organic sediment, with sites with less stock having relatively greater increases in organic sediment.

For the relationship between riparian vegetation and percent change in *E. coli* concentration, neither of the Vegetation PCA Axes were significant predictors of percent *E. coli* change. For the model using the individual components¸ there was a significant negative relationship between scrub cover and increasing *E. coli* concentrations; sites with more scrub in the riparian zone had smaller percent increases in *E. coli*. As with the original model using the SHMAK bank vegetation score, Panel and stock presence were both still significant predictors of *E coli* concentration change.

Finally, the relationship between riparian vegetation and percent change in coliform concentrations was exactly the same as for *E. coli* concentrations; neither of the Vegetation PCA Axes were significant predictors of percent coliform change. Similarly, for the model using the individual components¸ there was a significant negative relationship between scrub cover and increasing coliform concentrations; sites with more scrub in the riparian zone had smaller percent increases in coliforms. As with the original model using the SHMAK bank vegetation score, Panel and stock presence were both still significant predictors of coliform concentration change.

Table 36: Results of Generalized Linear Models (GLM) run to predict percent change in multivariate indicators of water clarity and quality on ARGOS dairy farms. For an explanation of the analysis and the table headings, see Table 29.

Response Variable	**Best model**	**R^2**	**Significance test**	**P value**	**Parameters**	**Parameter estimates (s.e.)**	**Students t**
Percent change in shmak score	Constant + Fencing	3.3	$F_{1,22} = 1.46$	0.237	Constant	66.3 (28.4)	2.34^{**}
					Fencing	-5.57 (4.49)	-1.21^{ns}
Clarity PCA Axis 1	Constant + Stock access	60.4	$F_{1,8} = 14.70$	0.005	Constant	-0.87 (0.32)	-2.74^{**}
					Stock access	0.26 (0.07)	3.84^{***}
Clarity PCA Axis 2	Constant + Fencing + Stock access	35.5	$F_{2,7} = 3.47$	0.09	Constant	-0.41 (0.39)	-0.11^{ns}
					Stock access	0.41 (0.16)	2.63^{**}
					Fencing	-0.31 (0.13)	-2.35^{**}
Nutrient PCA Axis 1	Constant + Stock access	1.3	$F_{1,10} = 1.15$	0.31	Constant	0.5 (0.62)	0.81^{ns}
					Stock access	-0.13 (0.12)	-1.07^{ns}
Nutrient PCA Axis 2	Constant + Panel + Fencing + Stock access	23.8	$F_{3,8} = 2.15$	0.17	Constant	00.13 (0.48)	-0.28^{ns}
					Panel C	1.13 (0.75)	1.15^{ns}
					Fencing	0.39 (0.15)	2.52^{**}
					Stock access	-0.38 (0.18)	-2.13^{*}

Table 37: Results of Generalized Linear Models (GLM) run to predict percent change in univariate indicators of water clarity and quality on ARGOS dairy farms. For an explanation of the analysis and the table headings, see Table 29 and 30.

Response Variable	**Best model**	**R^2**	**Significance test**	**P value**	**Parameters**	**Parameter estimates (s.e.)**	**Students t**
Percent temperature change	Constant+ Bank vegetation	0.4	$F_{1,13} = 1.06$	0.321	Constant	-5.69 (5.45)	-1.04^{ns}
					Bank vegetation	0.88 (0.85)	1.03^{ns}
Percent change $NO_2 + NO_3$	Constant+ Fencing	4.1	$F_{1,11} = 1.51$	0.245	Constant	-19.2 (17.6)	-1.09^{ns}
					Fencing	4.03 (3.28)	1.23^{ns}
Percent change NH_4^+	Constant+ Panel	12.2	$F_{1,11} = 2.67$	0.13	Constant	65.1 (36.2)	1.80^{*}
					Conventional	-86.9 (53.2)	-1.63^{ns}
Percent change DRP	Constant+ Panel+ Fencing+ Stock access	18.4	$F_{3,9} = 1.90$	0.20	Constant	142 (291)	0.49^{ns}
					Conventional	-827 (429)	-1.93^{*}
					Fencing	-167.2 (85.6)	-1.95^{*}
					Stock access	241 (107)	2.25^{**}
Percent change TOC	Constant+ Stock access	1.2	$F_{1,11} = 1.15$	0.307	Constant	-3.4 (11.3)	-0.30^{ns}
					Stock access	2.14 (2.0)	1.07^{ns}
Percent change Total P	Constant+ Bank vegetation+ stream bed	32.6	$F_{2,11} = 4.15$	0.045	Constant	18.7 (71.3)	0.26^{ns}
					Bank vegetation	-24.3 (12.5)	-1.94^{*}
					Stream bed	10.21 (3.65)	2.79^{**}
Percent change organic sediment	Constant+ Bank vegetation+ Stock presence	51.2	$F_{2,9} = 6.28$	0.016	Constant	1955 (1216)	1.61^{ns}
					Bank vegetation	574 (167)	3.44^{***}
					Stock presence	314 (134)	2.35^{**}
Percent change Total sediment	Constant+ Stock access + Stream bed	41.2	$F_{2,8} = 4.50$	0.049	Constant	163 (2171)	0.07^{ns}
					Stock access	1418 (476)	2.98^{**}
					Stream bed	419 (200)	2.09^{*}
Percent change clarity tube	Constant+ Panel + Stock access	23.5	$F_{2,11} = 2.99$	0.09	Constant	-28.4 (41.7)	-0.68^{ns}
					Panel – Conventional	-91.3 (55.8)	-1.63^{ns}
					Stock access	18.04 (7.6)	2.37^{**}
Percent change E. coli	Constant+ Panel + Bank vegetation + Stock presence	59.6	$F_{3,10} = 7.39$	0.007	Constant	3754 (2136)	1.76^{ns}
					Panel – Conventional	4267 (1531)	2.79^{**}
					Bank vegetation	-560 (290)	-1.93^{*}
					Stock presence	-1035 (231)	-4.47^{**}

Response Variable	Best model	R^2	Significance test	P value	Parameters	Parameter estimates (s.e.)	Students t
Percent change coliforms	Constant + Panel + Bank vegetation + Stock presence	59.9	$F_{3,10} = 7.48$	0.006	Constant	3805 (2125)	1.79^{ns}
					Panel – Conventional	4232 (1523)	2.78^{**}
					Bank vegetation	-563 (288)	-1.95^{*}
					Stock presence	-1038 (230)	-4.51^{***}

Table 38: Results of Generalized Linear Models (GLM) run to investigate the efficacy of the SHMAK bank vegetation score in predicting percent change in indicators of water clarity and quality on ARGOS dairy farms. For an explanation of the analysis see Table 31, and for a description of the other predictor variables used in the analysis, see the text and Table 29, and for an explanation of the table headings, see Table 29. For each model that contained the SHMAK bank vegetation score, the model was run replacing the bank vegetation score with the scores from the vegetation PCA analysis (see Table 27).

Response Variable	**Best model**	**R^2**	**Significance test**	**P value**	**Parameters**	**Parameter estimates (s.e.)**	**Students t**
Percent change Total P	Constant + Vegetation PCA Axis 1 + Vegetation PCA Axis 2 + Stream bed	38.4	$F_{3,10} = 3.70$	0.050	Constant	172.4 (42.9)	4.02^{***}
					Vegetation PCA Axis 1	-47.6 (19.8)	-2.40^{**}
					Vegetation PCA Axis 2	22.7 (27.8)	0.82^{ns}
					Stream bed	9.28 (3.54)	2.62^{**}
Percent change Total P	Constant + Pasture + Stream bed	41.4	$F_{2,11} = 5.59$	0.021	Constant	-150 (122)	-1.23^{ns}
					Pasture	4.66 (1.91)	2.44^{**}
					Stream bed	10.45 (3.34)	3.13^{***}
Percent change organic sediment	Constant + Vegetation PCA Axis 1 + Vegetation PCA Axis 2 + Stock presence	58.6	$F_{3,8} = 6.20$	0.018	Constant	-690 (1177)	-0.59^{ns}
					Vegetation PCA Axis 1	996 (258)	3.87^{***}
					Vegetation PCA Axis 2	-776 (573)	-1.35^{ns}
					Stock presence	181 (143)	1.27^{ns}
Percent change organic sediment	Constant + Pasture + Scrub + Stock presence	79.2	$F_{3,8} = 14.96$	0.001	Constant	15167 (3749)	4.05^{***}
					Pasture	-200.1 (40.7)	-4.91^{***}
					Scrub	-509 (192)	-2.65^{**}
					Stock presence	293.6 (85.1)	3.45^{***}
Percent change E. coli	Constant + Panel + Vegetation PCA Axis 1 + Vegetation PCA Axis 2 + Stock presence	55.3	$F_{4,9} = 5.03$	0.021	Constant	7571 (2365)	3.20^{**}
					Panel – Conventional	4011 (2122)	1.89^{*}
					Vegetation PCA Axis 1	-875 (522)	-1.59^{ns}
					Vegetation PCA Axis 2	-416 (1069)	-0.39^{ns}
					Stock presence	-1065 (270)	-3.95^{***}
Percent change E. coli	Constant + Panel + Scrub + Stock presence	60.9	$F_{3,10} = 7.74$	0.006	Constant	9004 (2278)	3.95^{***}
					Panel - Conventional	4263 (1503)	2.84^{**}
					Scrub	-420 (205)	-2.04^{*}
					Stock presence	-996 (220)	-4.53^{***}

Response Variable	Best model	R^2	Significance test	P value	Parameters	Parameter estimates (s.e.)	Students t
Percent change coliforms	Constant + Panel + Vegetation PCA Axis 1 + Vegetation PCA Axis 2 + Stock presence	55.7	$F_{4,9} = 5.09$	0.020	Constant	7635 (2352)	3.25^{***}
					Panel – Conventional	3984 (2110)	1.89^{*}
					Vegetation PCA Axis 1	-882 (549)	-1.61^{ns}
					Vegetation PCA Axis 2	-411 (1063)	-0.39^{ns}
					Stock presence	-1068 (268)	-3.95^{***}
Percent change coliforms	Constant + Panel + Scrub + Stock presence	61.3	$F_{3,10} = 7.86$	0.005	Constant	9087 (2263)	4.01^{***}
					Panel – Conventional	4228 (1493)	2.83^{**}
					Scrub	-423 (204)	-2.07^{*}
					Stock presence	- 999 (218)	-4.57^{***}

4 Discussion

Water quality on a number of the surveyed farms has been affected by agricultural activities, and in a number of cases, these impacts are significant and breach national standards. Significant relationships exist between on-farm management and deteriorating water quality. For example, increased stock access to streams is associated with increasing nutrient loads at the farm scale. However, encouraging results include positive relationships between riparian vegetation and water clarity and a high number of dairy farms with significant stream segments fenced from stock access harboring healthy riparian forests.

Despite these and other clear findings of general stream health, tremendous variability exists between individual farm data, and few clear differences appear between clusters, panels, or sectors. Water quality and aquatic ecosystem functioning are the result of a wide range of factors acting at a range of spatial and temporal scales. Local geology and landform, land cover, land use and land management, stream order, catchment size and topography can all interact to influence in-stream conditions and processes (Parliamentary Commissioner for the Environment 2004). As a result, any one-off survey such as this one can only ever hope to capture a 'snap shot' of state and process, and may be limited in its ability to identify causal mechanisms or draw general conclusions. It is important to keep in mind that the clusters, sectors and panels are selected for their suitability in a long-term research agenda, and results will be discussed both in the context of the longitudinal study aims and to analyze current data to discover the nature and causes of stream health on ARGOS waterways.

4.1 The state of waterways on ARGOS sheep/beef and dairy farms

Water quality, riparian health and aquatic ecosystem function is generally moderate or poor in surveyed waterways. Several of the significant findings are discussed below:

Nutrients

The levels of nutrients and sediment in waterways were highly variable between individual farms, clusters and farming sectors. Average levels of NH_4^+, NO_2 + NO_3, DRP and TP were higher on dairy farms than sheep/beef farms (Table 7), a finding consistent with the results from other studies (Ministry for the Environment 1997; Parliamentary Commissioner for the Environment 2004). Within the dairy farms, no farms exceeded the National Standards of nitrate and nitrite for Drinking Water of 11.3 mg/L (Ministry of Health 2005), although one farm had levels (7.5 mg/L) that exceeded the limits for increased monitoring requirements (set at 5.65 mg/L). Five dairy farms exceeded the Australian and New Zealand Environment and Conservation Council guidelines for nitrate and nitrite for minimizing impacts to aquatic ecosystems of 444 ug/L, two farms exceeded the limit of 30 ug/L for DRP and all farms exceeded the standard for NH_4^+ of 21 ug/L (ANZECC 2000). Levels of nitrate and nitrite and ammonium did not exceed drinking water standards on any of the sheep/beef farms surveyed, although seven farms did exceed the ANZECC standards for nitrate and nitrite, while three exceeded the standards for ammonium and two exceeded the standards for DRP.

Water clarity

Ten dairy farms and ten sheep/beef farms exceeded minimum water clarity standards (turbidity measurements) under the Resource Management Act, and four dairy and one sheep/beef properties exceeded the thresholds set for minimizing impacts on aquatic life (ANZECC 2000).

Invertebrate and periphyton communities

Invertebrate and periphyton communities were typical of modified or enriched waterways, with the invertebrate community dominated by taxa such as Oligochaete worms, flatworms and snails, while ephemeroptera (mayflies), plecoptera (stoneflies) and trichoptera (caddisflies) were uncommon in most streams. Similarly, long filamentous algae and thick algal mats, indicative of high light levels and nutrient enrichment (Ministry for the Environment 1992; Biggs, Kilroy et al. 1998) were commonly recorded in the survey. It should be noted that the invertebrate community will be affected by stream order, underlying geology, and instream productivity as well as modification or enrichment due to agriculture or other landuse, while periphyton communities will similarly be affected by factors such as light levels, catchment geology, water chemistry and temperature, stream substrate and nutrient levels (Biggs, Kilroy et al. 1998; Dodds 2002; Kalff 2002). Both invertebrate and periphyton community indices can provide better indications of long term conditions and impacts (Stark 1985; Metcalfe 1989; Joy and Death 2003; Hall and Killen 2005; Mancini, Formichetti et al. 2005) that short term measures such as clarity readings. The findings of our survey are in agreement with those of other studies that have found lower invertebrate scores (fewer insects, more worms, chironomids (midges) and mollusks) indicating more modified stream systems in agricultural streams compared to forested (Collier 1995; Quinn, Cooper et al. 1997; Townsend, Arbuckle et al. 1997) or buffered streams (Quinn, Williamson et al. 1992; Storey and Cowley 1997; Scarsbrook and Halliday 1999). The reason for the finding of significantly more bivalves on organic sheep/beef farms than either IM or conventional farms is unclear at this stage, as there were no significant differences in stream substrate, sediment levels or nutrients that would explain this difference. However, it is hoped that the surveying in summer 2006/07 will help clarify this situation. Overall, it appears that broad invertebrate and periphyton community indices can reflect long term and large scale processes in farm streams, but it is not clear if they can indicate changes in water quality or ecosystem functioning at the within-farm scale.

Micro-organisms

The average levels of *E. coli* and fecal coliforms in waterways on the ARGOS dairy farms were 4.6 and 6.3 times respectively the accepted levels for recreational water use (medium value 126 cfu/100 ml; (ANZECC 2000). Concentrations of *E. coli* and coliforms were highly variable between farms, but in some cases were over 2,500 cfu/100 ml, 20 times the accepted limit. Concentrations of *E. coli* of between 200 – 500 cfu/100 ml were recorded on 72 % of the farms, levels that have been shown to be positively associated with significantly elevated concentrations of *Campylobacter*, the most common cause of gastroenteritis in humans (Parliamentary Commissioner for the Environment 2004).

Two important findings related to the longitudinal aspects of this study are worth noting: 1) these data suggest stream health is affected at the farm scale by management activities; and 2) there were no consistent patterns in relative changes in measured parameters between different clusters, farm management systems or farming sectors.

The first is important as average levels of parameters do no isolate the positive or negative impacts of individual farming operations and farm-scale actions on water quality, and are of less use to farmers when they try to identify problems or measure the effectiveness of solutions. For this purpose, percentage changes in parameters across individual farms are of more value, and provide information that will allow farmers to manage their waterways to achieve benefits both for themselves and downstream users.
The second suggests that no particular management system (Organic, IM or Conventional farm management) provides an overall prescription for improved water quality. Rather, our findings and analysis suggests that maximizing waterway quality and functioning is a complex multi-dimensional affair that is highly context dependant, with different solutions required to different threats.

While these are expected findings of a one-off study, the variability between farms reduces the power of a single season assessment to discover the causes of changes in stream health. The longitudinal nature of the ARGOS project intends to overcome this weakness.

Nevertheless, the large number of waterways sampled in this survey and the replicated experimental design provides the best possible opportunity to discover broad patterns in water quality and ecosystem function on New Zealand sheep/beef and dairy farms, and to identify areas for future specific study. The survey also allows us to identify pattern and process at the farm scale, thus providing tangible scientific knowledge for farmers and land managers that relates to their own farm and management actions.

In the following section, we discuss the factors affecting farm-scale change in selected pollutants and threats to water quality on ARGOS sheep/beef and dairy farms.

4.2 Predicting farm-scale change in water quality indicators

<u>Nitrogen:</u> In agricultural systems, the majority of nitrogen enters the stream as nitrogen oxides (NO_2 + NO_3), as these are readily dissolved and can enter via surface runoff or groundwater (Kalff 2002). Sources of nitrogen include excess fertilizer application, excess production from legumes such as white clover, and animal wastes. Animal urine contains high levels of urea, which is generally converted to NO_3 by nitrification and then enters the stream in runoff or ground water. Urine is deposited on the soil in a compact “urine patch” at concentrations equivalent of up to approximately 1000 N/ha in some systems. Nitrogen readily converts to nitrate, and because it is deposited in concentrations in excess of pasture requirements, it is rapidly leached through the soil and into shallow groundwater and/or tile drains (Ministry for the Environment 2001). Subsurface flow is often the major source of N (as dissolved NO_3) into streams, particularly where there are tile drains (Muscutt, Harris et al. 1993). The problem is particularly bad in autumn and winter when plant demands are low and little N or P is taken up (Houlbrooke, Horne et al. 2004). In contrast, NH_4^+ readily binds to soil particles, so high soil erosion rates can also lead to large direct inputs of NH_4^+.

The different paths of entry of the oxides of nitrogen (NO_X) and NH_4^+ mean that different approaches are required to minimize their access to and influence on waterways. In the dairy sector, the shift from direct release of dairy-shed effluent to land-based application of farm dairy effluent (FDE) has greatly reduced point source nitrogen pollution, although there is still the potential for NO_X to enter waterways through subsurface flows or groundwater if excess effluent is applied. Average rates of loss of N from FDE are between 1-10 % of the applied total, while in some studies, up to 20% of both the N and P spray irrigated onto land can be leached through the mole and tile drainage system during the drainage events (Houlbrooke, Horne et al. 2004).

Well buffered riparian zones, with a high biomass of woody vegetation with a well developed root zone are considered most effective at preventing NO_X from entering waterways, by raising the water table and providing anaerobic conditions for denitrification (Pinay and Decamps 1988), providing organic material to assist in assimilation and denitrification (Fenessy and Cronk 1997), and through direct uptake by riparian vegetation (Vought et al 1994; Fennesry and Cronk 1997). However, riparian zones may not be effective at buffering streams against NO_X inputs in agricultural systems where sub-surface drains are present. In these situations, the majority of NO_X will bypass the riparian zone and enter the stream directly (Houlbrooke, Horne et al. 2004). Fencing to reduce direct stock access to the stream can also reduce direct inputs of wastes, and can significantly reduce NO_X levels in streams (Line, Harman et al. 2000).

In comparison, most NH_4^+ enters streams bound to sediments, and consequently practices that reduce sediment input can also reduce levels of NH_4^+ in waterways. Buffer strips with dense ground cover that reduce surface water velocity and increase sediment deposition have been shown to significantly reduce sediment input into streams (Muscutt, Harris et al. 1993; Hook 2003), while fencing to prevent stock access can reduce bank erosion and sedimentation rates (Owens, Edwards et al. 1996; Byers, Cabrera et al. 2005) and hence NH_4^+ input rates.

In the current study, we found a significant positive relationship between stock access into streams and increasing levels of NO_X in waterways in ARGOS sheep/beef farms, suggesting that direct input of wastes is a major source of NO_X contamination in these systems. We also found significant positive relationships between the amount of herbaceous vegetation cover, in the form of pasture and tussock/ungrazed pasture, and smaller relative increases in NH_4^+ on ARGOS sheep/beef farms. Sites with better stream bed scores, indicating lower levels of sediment in the stream, also had relatively smaller increases in NO_X. For this farming sector, fencing of waterways and the retention of grassy buffer strips appear to be the most effective way of reducing nitrogen inputs on ARGOS sheep/beef farms. Twenty one of the surveyed streams had no fencing at all and only five had effective fencing for more than 50 % of the stream length. Consequently, there is great potential for managing nitrogen inputs. If temporary fencing was erected, or gates to allow access to the riparian buffer were included, then the potential for mowing for hay or grazing of the grassy strip at times of low flow and rainfall when risks of nitrogen input are low would still be possible.

It is not possible to prescribe the required dimensions of a grassy strip, as the exact requirements will be context dependant, and will be influenced by topography, rainfall, soil type and stocking rates and farm management (Hook 2003). In areas with low elevation and low stocking rates, grassy buffers of 1-3 m width can intercept over 90 % of the sediment entering streams (see Hook 2003), while in steeper catchments, or areas with higher stocking rates, buffers may need to be wider. Nevertheless, the opportunities to utilize the grassy strip for feed at appropriate times would still exist.

Despite discovering a few significant relationships, we were not able to identify the factors generally influencing change in nitrogen across the dairy farms in our study. This is probably the result of two factors. The results of any one-off study can be expected to be highly influenced by recent climatic conditions and management actions, and it is possible that such variation will reduce that statistical power of any tests and the ability to predict change. Additionally, it is possible that we have not measured the important causal variables at operation in the system, and so have no ability to predict change. We plan a repeat survey of the streams in summer 2006/07 to gain information on inter-annual variation in water quality parameters, and increase the statistical power of our analyses. The solution to the second problem requires careful consideration of what variables may be important that involves all stakeholders, and should not rely on simply adding more variables and hoping a solution will appear in the analysis (Burnham & Anderson 2002). Potentially important variable that we did not include in these analyses were the presence of sub-surface drains feeding into the waterways we sampled and short-term stock management in the riparian area or adjacent pastures. Tile and mole drains are known to have significant effects on water quality and aquatic ecosystem functioning (Donnison and Ross 2003; Houlbrooke, Horne et al. 2004; Oliver, Heathwaite et al. 2005). As an example of their importance, one of the sheep/beef properties had a 730 % increase in NO_X across the farm in a stream that lies at low elevation on the property and is fed extensively by tile drains (although absolute values of NO_X were well below critical levels: average concentration = 496 ug/L). Tile drains are present on many farms in poor draining areas and may be a major influence on nitrogen inputs and fluxes in waterways on ARGOS farms. Additionally, recent stock grazing patterns can influence inputs of nutrients and other pollution into waterways, and can have a major influence on one-off studies. Consequently, information on the presence of tile drains and stock rotations is currently being collected from all farms in the study (particularly in the dairy sector where rotations are more regular than on sheep/beef farms) and both will be included in future analyses to help clarify the paths of entry for pollutants.

<u>Phosphorous:</u> Phosphorous readily binds to soil particles (Kalff 2002), and it is estimated that from 50 % (Vaithiyanathan and Correll 1992; Cooke and Prepas 1998) to over 80 % (Kalff 2002) of phosphorous enters streams bound to sediments, with only ~15 % entering the stream as DRP. As with nitrogen, phosphorous is one of the major limiting factors for plant growth, and increased levels in waterways can lead to problems of increased algal and plant growth, reduced habitat for some invertebrates and fish, and risks to stock and human health. Phosphorous tends to stay bound to sediment in aerobic conditions, but as Oxygen levels drop (e.g. as temperatures rise) more P is released back into the water column in a dissolved usable form (Dodds 2002; Kalff 2002). A greater surface area of stream bed can lead to more sedimentation and more bound P being retained in a reach. Small streams tend to have relatively higher stream bed surface areas and thus trap relatively more sediment and bound nutrients. Consequently, levels of available phosphorous will depend on the interplay between inputs onto the surrounding system, pathways of access into the waterway and instream conditions. The most effective ways to reduce inputs of phosphorous into waterways is to control inputs of sediment, for example fencing to reduce stock access (erosion of banks and some direct deposition: (Owens, Edwards et al. 1996; Byers, Cabrera et al. 2005) and increasing vegetation buffers to trap incoming sediment (Smith 1987; Hook 2003; McKergow, Weaver et al. 2003). Riparian zones with more vegetation, in particular woody vegetation, are potentially more effective at removing dissolved reactive phosphorous (DRP) moving through the zone as subsurface flow, as a result of direct uptake.

From the current study, there was some evidence that on-farm management was effective at reducing phosphorous loads into waterways. Sheep/beef farms with more tussock, rank grass and trees had smaller relative increases in DRP across the farm, while dairy farms with more grazed pasture along the waterway, and more complex streambeds with greater surface area had relatively greater increases in total phosphorous. Consequently, it is likely that denser riparian vegetation that contains a mix of woody vegetation and dense ground cover provides a good barrier to both DRP and sediment-bound phosphorous. There was also a significant relationship on the sheep/beef farms between less stock access to waterways and greater relative increases in total phosphorous across the farm. The mechanism behind this relationship is not clear, but may relate to less disturbance of the sediment by stock and thus less sediment and phosphorous export from the reach (McKergow, Weaver et al. 2003). It is hoped that the additional sampling planned for summer 2006/2007 will clarify the situation. As with levels of NO_X in streams, it is possible that the presence of subsurface drains has a significant influence on levels of DRP in stream in the study; this requires further investigation.

Sediment: Increased rates of sediment input into streams have been rated as one of the most severe water quality impacts of agriculture in New Zealand (Sinner 1992; Ministry for the Environment 2001; Parliamentary Commissioner for the Environment 2004). Current sources of sediment include direct bank erosion by stock and water and wind erosion of bare soils (Ministry for the Environment 1997; Ministry for the Environment 2001; Canterbury 2005). Increased sediment levels in waterways can reduce water clarity and primary production, cover substrate and reduce habitat for invertebrates and fish (Davies-Colley, Hickley et al. 1992; Quinn, Davies-Colley et al. 1992; Rabeni and Smale 1995; Quinn, Cooper et al. 1997; Wood and Armitage 1997; Nakamura and Yamada 2003; Zimmerman, Vondracek et al. 2003; St-Hilaire, Caissie et al. 2005; Francoeur and Biggs 2006), and, as outlined above, are a major source of phosphorous (Vaithiyanathan and Correll 1992; Cooke and Prepas 1998; Kalff 2002). The most effective ways to reduce inputs of sediment are to increase fencing to reduce stock access (erosion of banks and some direct deposition: (Owens, Edwards et al. 1996; Byers, Cabrera et al. 2005) and increasing vegetation buffers to trap incoming sediment (Smith 1987; Hook 2003; McKergow, Weaver et al. 2003).

It is not entirely clear what is affecting sediment loading into streams on the farms in this study. On the sheep/beef farms, sites with more trees, scrub and tussock, and less pasture tended to have greater relative increases in sediment. There are two possible mechanisms that may explain this relationship. It is possible that waterways that have more woody, complex riparian vegetation are more effective at stopping suspended sediment transported from upstream sites, resulting in increased sediment along the reach and increased water clarity (Parkyn, Davies-Colley et al. 2003). On the ARGOS dairy farms, streams with better stream bed scores and more surface area had relatively greater increases in sediment, and finding found elsewhere (Dodds 2002; Kalff 2002). It is also possible that these sites are associated with reduced stock access to the stream, resulted in less disturbance and more opportunity for sediment to settle within the reach. Sites with less stock access did have greater relative increases in sediment across the farm, although there was no corresponding positive relationship between increasing sediment levels and increasing water clarity across the farm. An alternative explanation is that sites with more woody vegetation and increased shade may actually have increased rates of sediment input into the stream, due to a reduction of ground cover in the lower light conditions (Davies-Colley 1997; Trimble 1997 ; Parkyn, Davies-Colley et al. 2005).

Thus, the amount of sediment present is directly related to the amount entering the waterway. It is not currently clear which mechanism is in operation on the sheep/beef farms. If the riparian zone is effectively stopping sediment input, so that increases in sediment on the substrate represent settling of suspended sediment, then we should see a positive relationship between increasing sediment levels and increased water clarity. Conversely, if woody riparian vegetation is ineffective at preventing sediment input due to a bare understory, then we would expect a negative relationship, with increasing sediment levels leading to decreasing water clarity. However, there was no relationship between relative change in water clarity across the farm and changes in sediment levels to help clarify this situation.

Microbes in dairy waterways: Our findings of elevated levels of *E. Coli* and faecal coliforms in many dairy waterways is cause for concern. Micro-organisms that pose health risks to humans are carried by many livestock, particularly cattle (Donnison and Ross 2003; Houlbrooke, Horne et al. 2004), and can enter waterways either via surface runoff or via infiltration through the soil profile into groundwater (Aislabie, Smith et al. 2001; Rodgers, Soulsby et al. 2003). Longer retention times of micro-organisms in the soil can result in reduced pathogenicity and less risks to water quality and human health. Mechanisms to reduce micro-organism entry into water include fencing to prevent stock access (Byers, Cabrera et al. 2005), reduction of sediment input, and careful management of effluent disposal (Houlbrooke, Horne et al. 2004).

In the current study we found that streams with more direct stock access had greater relative increases in micro-organisms, reinforcing the need to exclude stock from waterways to prevent microbial contamination. We also found a significant difference between converting Organic and Conventional dairy farms, with Conventional farms have significantly higher levels of microbial contamination. We have no information in this study on relative levels of infection by *E. coli* and coliforms in cattle on Conventional and Organic Conversion dairy farms, and consequently cannot comment on whether animal health may be different between the two panels. However, there was more evidence of stock access into waterways on conventional than converting organic farms, although these differences were not significant, and so the differences in microbial contamination levels in waterways between the panels may reflect differences in waterway management under the two systems. It is anticipated that discussions with individual farmers by the social and farm management objectives of the ARGOS project will help to clarify this situation.

There was also a significant relationship between increasing scrub cover and smaller relative increases in *E. coli* and coliforms. The reason for this relationship is not currently clear, but may result from increased sediment trapping at sites with more scrub, defined here as low dense woody vegetation. It is also possible that dense stands of scrub effectively restrict stock access and thus direct deposition of fecal material into the waterway. It is hoped that data on micro-organisms from the upcoming survey in summer 2006/07 can be combined with more detailed information on stock access and behaviour in the riparian zone can be combined to clarify this situation. In particular, the interactions between stock movements and behaviours and different vegetation types and barriers are vital in understanding the best ways to minimize microbial contamination of waterways. Installing effective barriers to stock access would greatly reduce inputs of microbes into waterways, while also reducing inputs of NO_X, phosphorous and sediment at the same time.

General Observations on Stream Health: We were not able to identify any factors that predicted change in a number of water quality indicators across individual ARGOS sheep/beef farms. We may have expected to see relationships between the nature and extent of riparian vegetation and changes in TOC, temperature and dissolved oxygen, with sites with more woody vegetation and shading expected to be cooler with higher levels of dissolved oxygen and organic carbon, but our data do not reveal such clear interactions between variables. We also failed to find any farm-scale effects on the periphyton or invertebrate communities using the SHMAK indices or multivariate indicators, although there were some relationships with farm management systems, stream characteristics and riparian vegetation when additional indices such as the percent of EPT or insects in the macro-invertebrate community were used.

Overall, this suggests that changes in these parameters may occur over larger scales than the individual farm. It must be reiterated that we only currently have data from one sampling round, and additional surveys are required before these conclusions can be confirmed or rejected. Similarly, if the riparian habitat or stream characteristics are similar across the entire farm, then invertebrate or periphyton communities may be significantly different to those in sites further up or downstream, but this effect will not be apparent when considering percent change across a farm. We expect that our long-term repeated surveys will account for variability between individual farms and individual farm management practices to reveal underlying differences between clusters, panels and sectors. We also expect to improve our ability to explain change, particularly among variable such as periphyton and invertebrate communities that are better indicators of long-term trends in farm management and water quality.

4.3 Calibration of SHMAK

The SHMAK assessment kit has been developed specifically to provide an easy to use, scientifically-based, monitoring tool for landholders (Biggs, Kilroy et al. 1998). The kit is designed to allow individuals to monitor long-term change at pre-selected sites, although when sites are carefully selected, there is no reason why it can't be used to look at relative change across a farm. However, a number of researchers have expressed skepticism that the SHMAK kit is precise and sensitive enough to detect changes in waterways, and very little additional validation of the technique has been carried out (for an example see Kilroy and Biggs 2002). In addition and possibly because of this situation, uptake and use of the kit by landholders to date has not been extensive. Indeed, none of the ARGOS farmers had used the SHMAK kit or undertaken any stream monitoring prior to our survey. It is not clear if this reflects a lack of knowledge of the kits availability and usefulness amongst landholders, a lack of awareness that there are potential impacts of farm management practices on water quality that require monitoring, a lack of promotion of the SHMAK kit and the need to monitor by regional authorities and industry, or widespread knowledge of the kit but skepticism of its validity or usefulness.

Our study was interested in testing the accuracy and reliability of the SHMAK kit as an indicator of the impacts of farm management on water quality at the farm scale, and whether it can be used by farmers to help with operational decision making. Our results suggest that aspects of the SHMAK assessment protocols can provide accurate and useful indicators of changes in water quality at the farm scale, while other parts may not be sensitive enough for this purpose. For example, sites with higher stream bed scores, indicating a greater proportion of the substrate is made up of cobbles and boulders, had increased rates of sediment and bound nutrient deposition. There were also positive relationships between the stream bed score and indicators of healthy macro-invertebrate communities (proportions of ephemeroptera, plecoptera, trichoptera and insects).

The SHMAK bank vegetation can also significantly predict change in sediment and nutrient loading, although the causal mechanisms are not always clear. Increasing cover of pasture and bare ground gives a lower score for the index, while sites with more trees, scrub and tussock score higher on the index (Biggs, Kilroy et al. 1998). However, different riparian vegetation components are more effective at reducing impacts from different pollutants, so that a site with trees and scrub but little ground cover will score highly in the SHMAK assessment and may be effective at reducing inputs of NO_X and DRP due to direct uptake or nutrients in the root zone. However, sites with increased woody vegetation generally have higher levels of shade, which can reduce instream biomass of periphyton and macrophytes. Such sites may actually export greater concentrations of dissolved nutrients, as less are taken up for plant growth (Wilcock, Scarsbrook et al. 2002

; Parkyn, Davies-Colley et al. 2005).

In addition, sites with extensive woody vegetation but sparse ground cover may not be as effective at reducing sediment, NH_4^+ and phosphorous inputs as those with grassy buffers (Ministry for the Environment 2001; Hook 2003; Blanco-Canqui, Gantzer et al. 2004). If inputs of sediment or bound nutrients are affecting periphyton or invertebrate levels, then overall stream health may be decreasing in spite of a good SHMAK assessment. Additionally, a relative index of overall riparian vegetation is harder for landholders to use when planning specific management actions. It is easier to aim to increase cover of rank grass or trees for example, or to reduce the amount of bare ground on the stream banks than it is to achieve a specific bank vegetation score. For effective management of riparian zones to achieve waterway protection and enhancement, while still maximizing productivity, it may be necessary to ensure individual landholders understand how different types of vegetation can increase or reduce particular pollution risks. Armed with such knowledge, they can then best balance management objectives and actions, negative impacts and opportunities for improved water quality to ensure both they and downstream stakeholders gain maximum protection of and benefit from agricultural waterways.

The SHMAK macroinvertebrate and periphyton scores for individual farms were in agreement with our additional metrics, and appeared to successfully reflect overall community structure and instream conditions. However, neither of the SHMAK scores was sensitive enough to highlight the farm scale effects of habitat, management or nutrient and sediment changes, at least in our one-off study. It is possible that repeated SHMAK sampling at the same sites will detect any increase or decrease in water quality, as the assessment kit is designed to do (Biggs, Kilroy et al. 1998). As with the bank vegetation score, we would suggest that landholders that use the SHMAK kit are encouraged to also consider changes in individual taxa, and assisted to gain an understanding of what is ‘normal’ or ‘ideal’ for their particular waterway so they can better identify and understand any changes in water and stream quality.

The overall SHMAK score and the individual components did not show significant changes across the study farms, suggesting at face value that there are no positive or negative impacts of farm management at the farm scale. Conversely, a number of the additional measurements we recorded as calibration, including NO_X, DRP, and TP and sediment levels, did show farm-scale trends. Although the SHMAK scores were not sensitive enough to detect increases or decreases in water quality and ecosystem functioning across individual farms, some of them (particularly the stream bed and bank vegetation scores) but is useful as a predictors of increasing or decreasing levels of nutrients, sediment and microbes. For example, if individual landholders plant woody vegetation or allow pasture to remain ungrazed over the autumn and winter months, and record increases in the bank vegetation score, they can be fairly confident that levels of sediment and nutrients will be reduced on their own farm. In addition, if such actions are combined with exclusion of stock from the waterway, then individual farmers and landholders can also expect benefits including increased stock health (and reduced expense) if the waterway is used for livestock watering, reduced risk to human health if the waterway is used for recreation or drinking water supplies, and increased aesthetic values.

5 Conclusions and recommendations

Our findings are consistent with other studies and research demonstrating that water chemistry, community structure and ecosystem functioning are vastly different between agricultural waterways and those in unmodified habitats. However, we also found evidence that water quality and instream conditions can change and improve at the farm scale. While it is difficult to separate the effects of historical large-scale changes in land cover and management from those of current practices, our findings suggest that there is potential for landholders to implement management actions that can result in protected or improved water quality within their own property boundaries, as well providing downstream benefits to other stakeholders.

In our study of water quality and aquatic ecosystem functioning on ARGOS sheep/beef and dairy farms, we found evidence of different levels of pollution in different farming sectors, which higher levels of nutrients in waterways on dairy farms than on sheep/beef properties. This reflects more intensive practices in the dairy sector, with higher fertilizer inputs, stocking rates and production. However, we did not consistently find larger relative increases in nutrients or other pollutants across individual dairy farms. In some cases, management actions to prevent harmful impacts on streams, such as fencing to exclude stock, were more common in the dairy sector than sheep/beef. Additionally, we found very few differences in stream state or functioning between different farm management systems, with most differences instead relating to individual farm management decisions.

The SHMAK assessment kit did not detect overall changes in stream health and functioning across individual farms, suggesting faming practices are not having an impact at the farm-scale. We did record some changes in nutrient levels, sediment levels and other physical and biotic parameters across the study farms. However, we do not know at this stage if these changes are affecting ecosystem state and functioning, and whether the SHMAK assessment is too insensitive. Conversely, we do not know if our additional measurements are picking up statistically important but biologically trivial differences in parameters, and that in fact the SHMAK assessments are giving a more accurate picture of overall stream functioning at the farm scale.

The conclusions from this study are only tentative, based as they are on only one survey per farm, and with information lacking on several potentially important variables. A second round of sampling in summer 2006/2007 will allow us to better control for inter-annual variation in water quality measurements, and give greater statistical power to detect the mechanisms driving improvements or declines in stream health and functioning. Additional variables will also be included in future analyses, including information on stock rotations preceding, and at the time of the survey, and the presence of subsurface drains on the sampled waterways. The inclusion of these variables will allow us to both re-evaluate the results of this current survey, and better understand the factors affecting waterways on ARGOS farms in the future.

One of the most crucial parts of the entire project is the continuation of dialogue between the researchers and the individual farmers in the project. The third specific aim of the study is to combine scientific information on the state and functioning of the waterway, with the social, economic and environmental objectives of the farmer, to ensure the ongoing sustainability of the entire farming operation. The results of this first survey will be disseminated to each farmer, including the state of waterways on their own farm, comparison data from other farms in the sector, and information on what factors or actions are affecting these results. With the addition of data from the surveys in summer 2006/07, we can begin to work with individual farmers, to ensure they have cost effective ways to manage waterways on their farms that provide social, economic and environmental benefits.

6 Recommendations

Repeat stream monitoring in subsequent years. The cluster, panel and sector research design has proved to be poor at discovering the causes of variability in stream health between individual farms, and discovered few differences between Organic, IM and Conventional farms, yet is strategically designed to monitor change over time to reveal underlying differences between these farming systems. Another survey will be conducted in 2006/2007, and we strongly recommend repeating surveys annually or bi-annually if possible for the lifespan of the project – potentially 20 to 30 years.

Link stream health data to economic, social and farm management data generated by ARGOS. This survey identified gaps in knowledge that weaken the explanatory power of the surveys. For example, information about stock management in adjacent pastures and the location of tile drains have a major impact on stream health. Information about pasture and stock management will be compiled by the social team and our GIS capacity will help map important management features such as tile drains for inclusion in future analysis.

Provide feedback directly to farmers and assist with the development of watercourse management plans. ARGOS is designed to facilitate improved environmental, economic and social health on New Zealand farms. The results of this survey have identified important impacts to water quality at the farm scale and linked several key indicators to farm management practices. The ARGOS research design includes industry representatives who have personal relationships with each of our participating farm families and can provide direct and meaningful feedback and advice based on the findings of stream health monitoring. This process must begin immediately and continue for the duration of the research programme.

Continue to apply SHMAK protocols alongside ARGOS stream monitoring protocols. We hope to discover the power of the SHMAK Kit to measure and explain changes in stream health at the farm scale. Our research will provide valuable feedback on this issue, and make recommendations on improvements to the SHMAK design.

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